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# Minicar Transit System Final Report

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# Minicar Transit System Final Report

## **Disciplines**

Engineering | Systems Engineering | Transportation Engineering

MINICAR TRANSIT SYSTEM

Final Report

1970

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## FOREWORD

Project History and Organization. The Minicar Project was started in June 1967 by the University of Pennsylvania under the sponsorship of the Urban Mass Transportation Administration (UMTA) of the Department of Housing and Urban Development, and later of the Department of Transportation. Phase I of the Study was completed in December 1968 and its results were included in five reports of individual research teams and a Final Report, Phase I. Phase II was conducted between December 1968 and October 1969, when all major phases of research at the University were terminated by the sponsor. The work between November 1969 and April 1970 consisted only of research by Minicars, Inc., subcontractor to the University on this Project. The present Report, prepared between April and August 1970, contains results of research conducted by the University of Pennsylvania and Minicars, Inc. between December 1968 and termination of the Project.

The research at the University of Pennsylvania during 1967-1968 was organized through the Institute for Direct Energy Conversion in the Towne School of Civil and Mechanical Engineering. The subcontractor for vehicle development was GM Research Laboratories. Since the summer of 1968 the Project was organized through the Center for Urban Research and Experiment (CURE) at the University of Pennsylvania with Minicars, Inc. of Santa Barbara, California as subcontractor for vehicle development.

The Project initiator and Director from its beginning until 16 February 1970 was Dr. Manfred Altman. The leader of the GM and Minicar subcontractor's teams during the entire Project was Donald Friedman. After 16 February 1970, Professor Robert Mitchell, Director of CURE, assumed the charge of the completion of the Project. On 15 April 1970, Dr. Vukan Vuchic accepted the responsibility of preparing this Final Report. In the preparation of the Report he has been assisted by Messrs. Donald Bergmann, Bruce Douglas and Bondada Murthy, Research Assistants. Mr. Bergmann has participated in this work on a voluntary basis.

Research Teams. Research during the reported period was conducted by a multidisciplinary team at the University and at Minicars, Inc. The list of researchers is given in the beginning of this Report.

Some Comments on Project Conduct. Certain experiences and events which occurred during this Project are pertinent to mention here since they had a major impact on its course and results.

The Minicar Project was conceived and organized as an interdisciplinary research effort. While the team had the technical expertise required to cover all major research areas, serious problems developed in its organization. Communications among researchers as well as among the team, the sponsor, and other organizations related to the Project became so inadequate, that in March 1969 a major attempt to reorganize the Project was commenced by the UMTA, MITRE Corporation, Project Director from the University of Pennsylvania and President of Minicars, Inc. This reorganization of current research and planning of future research (for 1969-70) lasted until 30 September 1969, at which time the contract was discontinued by the sponsor.

Some areas of research were discontinued during the Project reorganization, such as planning of an experiment with the proposed Minicar Transit System and studies of the Systems's applicability to other cities. Each of these areas had absorbed a sizeable effort. In addition, the researchers were required to prepare extremely detailed plans for organization of future research. Then, before the new research phase started, the entire effort was discontinued.

Naturally, all these changes affected negatively the on-going research. While many of the major tasks were completed, some tasks remained unfinished. Consequently, research in several areas included in this Report has not been brought to conclusion and requires additional work.

While much of the research in this Study was accomplished by team effort, technical responsibility for the contents of the Report lies with the authors of Chapters and/or Technical Supplements as listed in the Table of Contents. Report editing has been the responsibility of Dr. Vukan Vuchic. Consequently, the contents of this Report reflect the views of its authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard specification or regulation.

Members of the research teams on the Minicar Study feel that this multidisciplinary work in the complex area of urban transportation has been an interesting and valuable experience. It is hoped that its results are of value for several systems related to it as well as for a better understanding of urban transportation in general. Participants in this research and the University of Pennsylvania wish to express their gratitude to the Urban Mass Transportation Administration of the Department of Transportation for its sponsorship of this Study.

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\*Tables included in Technical Supplements are prefixed by their respective supplement number.

## I. INTRODUCTION

Urban transportation is in serious need of expeditious practical innovation to meet the contemporary demands of America's cities. Existing transportation service is generally slow, costly, unreliable and unavailable to many persons who want to travel. These problems affect the users of transportation systems, as well as whole urban areas, and with them an increasing percentage of the nation's population.

The magnitude of the urban transportation problem is rapidly increasing. Its consequences are becoming more serious and widespread. Of even greater pertinence, it is clear that the continuation of existing trends will not lead to creation of a desirable urban environment, but rather to a further sharpening of the urban crisis. This realization has stimulated interest in exploration of both modified and new systems for urban transportation. This Project explores one of the proposed new concepts - the Minicar Transit System (MTS).

### A. The Minicar Project

The basic concept of the Minicar Project when it was initiated in 1967 was considerably different from the one that is reported here. The initiator of the Study conceived a system of small electrically-powered automobiles to be utilized for travel within the central areas of cities only. Numerous operational problems of such a system and its limited efficiency for short CBD trips were soon realized as limiting factors of this concept.

On the other hand, the two basic new concepts of the Minicar Transit System - individual travel by rental vehicles and specially designed vehicles for travel in urban areas - were retained throughout the Study. Each of them has obvious advantages and certain limitations. An attempt has been made to explore these characteristics of the MTS and find the potential role of such a system in urban transportation.

Due to the major impact which transportation has on urban mobility and the environment in general, this Study did not focus only on the development of the System, but also included rather detailed analyses of a number of different aspects of the System and the impacts it would have. For this reason, the Study was performed by a multidisciplinary team consisting of several research groups.

Some of the research tasks required only a limited amount of coordination with other tasks. For example, development of the vehicle had to be based on operational specifications, but beyond that point the work was relatively independent. Several major research tasks, however, were mutually closely interwoven: demand projections, economic aspects of the System and some of the System's physical and operational characteristics are an example. Strictly speaking, change of an assumption in any of these areas, such as operating costs or fare structure, should be followed by a new round of analyses of the System's economics, demand projections, operations, optimal fleet size, etc. Contacts among individual research teams were maintained throughout the Study, and a detailed round of analyses was done in the first phase of the research. However, a final round, which would have reconciled all later individual changes in assumptions and estimates, was not completed within the reported research period. Consequently, there remain some detailed differences in the assumptions among the materials presented in this Report which still require reconciliation. None of these differences, however, substantially affects the concept and evaluation of the MTS.

Despite these discrepancies between individual research efforts, as mentioned above, the Study has experienced considerable cooperation and interaction among different groups and individuals within the multidisciplinary research team. Consequently, behind most sections of this Report lies the independent as well as joint effort of different disciplines.

#### B. Purpose and Scope of the Study

The purpose of the Minicar Study was to analyze and plan for:

- a. Increased mobility (higher availability of transportation, speed reliability, convenience and/or reduced costs); and
- b. Reduced negative side effects (air pollution, space requirements, congestion, etc.) of individual transportation in urban areas,

by introducing a system specially designed and operated for such conditions - Minicar Transit System (MTS).

The basic goals of Phase I of this Study were to analyze the feasibility and desirability of introducing the MTS concept into urban areas. While the conclusions of that Phase were generally positive, there were uncertainties in several areas. Some of these uncertainties required additional theoretical study; others were of such a nature that they could not be resolved without an actual experiment with a limited-size system. This was particularly the case with demand projections, economic aspects and some operational features of the System. The former two would be particularly important for verification of the System's feasibility and desirability.

Consequently, the basic purpose of Phase II was to further develop the System concept, including a prototype vehicle, and to plan an experiment with an MTS of limited size. During the course of the Study a number of changes in scope were required, among which was indefinite postponement of the System experiment. The Study therefore focused on the analysis and design of the System in greater depth with respect to its operation and economics, as well as the role of such a system in urban transportation and its impact on urban life in general.

### C. Report Organization

Selection of material for this Report has been done primarily on the basis of its research value, its relevance for eventual continuation of this Study, and its validity for other urban transportation systems with similar characteristics. The amount of presented material therefore does not necessarily correspond to the extent of research effort: some major phases which required a significant work effort, such as planning of the experiment, have been omitted, while some others, such as development of the vehicle and legal aspects of the System, have been included with a fair amount of detail.

In general, however, to facilitate reading by broader technical circles, it has been considered desirable to avoid excessive length in this Report and to separate purely technical parts into Technical Supplements. The Report and the Technical Supplements have liberal references to technical papers and reports produced during the Project, a list of which is presented at the end of the Report.

All principal aspects of research accomplished prior to Phase II of the Minicar Project were included in the Final Report on Phase I [R-1]\*. Some of the basic findings from this previous research have been included in this Report for completeness and readers' convenience, although major repetitions have been avoided. For all technical details from Phase I the reader is referred to [R-1].

The first part of this Report summarizes the major findings and results of the entire Minicar Study. A concise definition of the System is given in Chapter II. It is followed by a summary of demand projections and an analysis of economic and organizational aspects of the System. The next two chapters discuss the expected impact of the MTS, its potential role in urban transportation and advantages and disadvantages of the concept. The last chapter summarizes the findings, gives evaluation of the MTS and presents recommendations for further steps.

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\* Numbers in square brackets [ ] indicate references given at the end of the Report.

Technical Supplements, representing the second part of this Report, contain summarized technical results of research in different areas performed by individual teams during Phase II of the Study.

## II. MTS DESCRIPTION

This Chapter presents a concise description of the MTS, summarizing its significant features and the general specifications developed within the Minicar Project.

### A. The System

The MTS consists of a set of terminals located at many points throughout a served area, and a fleet of specially designed vehicles-Minicars. Any person who satisfies certain requirements with respect to driving capability, insurability and credit can become an MTS user. The user has a credit card with an identification number which allows him to rent a Minicar at any one of the terminals for a single trip, or for an extended period of time, after which he can drop the Minicar off at that or any other terminal. In addition to the monthly-billed credit system, provisions for cash transaction can be incorporated into the System to extend service for such uses as tourist travel, airport access, etc.

The times and locations of the checking out and checking in of the vehicle are recorded and transferred via an information system to a central facility. Additional data collected automatically during check-in and -out procedures will be used to program maintenance work and indicate the need for redistribution of vehicles among the terminals to meet demand. Charges for the use of the Minicar are computed on the basis of time and vehicle mileage between the two check points. The user does not worry about the fueling and maintenance of the vehicle; the insurance is included in the charges.

### B. Vehicle

#### 1. General Requirements

In order to derive full benefits from the MTS for the users, the operator and the city, the vehicle has to be adapted to the requirements of its applications. Since Minicar use would differ considerably from operation of any other vehicle systems, it is clear that a vehicle of special design is called for.

Most Minicar operations will take place in urban areas. Consequently, the MTS will serve mostly relatively short trips; requirements for minimum parking space and reduction in exhaust pollution are of particular importance. Since the vehicles will be rented, they must be easily adaptable to use by



different drivers. In order to achieve optimum economy, vehicle maintenance procedures need extensive standardization. In summary, these operating characteristics, not being peculiar to any previously constructed vehicle, should be provided for by the special design.

## 2. Prototype Vehicle Development

The technical development and testing of a vehicle to conform with the MTS requirements was accomplished by Minicar Inc., through the construction and subsequent numerous alterations of two prototype vehicles. Prototype A was the first experimental vehicle and it was used to resolve many of the fundamental feasibility questions in engine performance, suspension, ride, handling, and safety features. Extensive experimentation was then conducted on the power unit. Subsequently a second experimental vehicle, Prototype B, was constructed to further optimize the power unit as well as additional components of the chassis and body. The basic technical aspects of the vehicle as developed in Phase II of the Minicar Project are presented in Technical Supplement S-I.

## 3. Basic Features

Designed as the shortest vehicle which still satisfies the requirements of performance, passenger comfort and safety, Minicar has an over-all length of nine feet. This is approximately one half of the average length of standard American cars. This dimension makes the car easy to handle in traffic and very convenient for parking. Since the Minicars will utilize standard lanes and should provide three seats, their width is comparable with standard automobiles: 78 inches; maximum outside height is 59 inches. The curb weight of the vehicle with full fuel tank and three passengers is estimated to be between 2750 and 3500 pounds. A Minicar prototype, developed within this Project, is shown in Figure 1.

For enhancement of MTS usage a pleasing exterior styling has been stressed. The interior of the vehicle requires design for safety, comfort, utility and easy maintenance. Seats are contoured and fixed in position, hand and foot controls are adjustable by a movable toe board. The general interior compartment is "quietly luxurious", parts are reasonably low-cost and easily replaceable. A rear luggage compartment is provided that accommodates up to three suitcases.

The vehicle chassis is of tubular construction with a very rigid frame circumscribing the passenger-driver area. The body is of Fiberglass Reinforced Plastic for reasons of optimum economy, strength, durability and finish.



FIGURE 1. MINICAR-PROTOTYPE B

Since the Minicars are planned to operate on existing streets and highways of all types, the requirements for their dynamic characteristics have been based on performance in street traffic and on freeways. Consequently, a high rate of initial acceleration and moderately high top speed (approx. 70 mph) are called for. On the other hand, for reasons of economy, minimum air pollution and noise, it is required that the motor be as small as possible. An additional consideration was that MTS was planned for reasonable early implementation, so that the power plant must be currently feasible, not requiring long research for new components. A hybrid system consisting of an internal combustion engine (ICE) and an electric motor have been selected as the optimal propulsion system for Minicars. Supplementary to the vehicle development, a separate theoretical study on the control system of the hybrid power train was conducted by the University of Pennsylvania. Details of this study are summarized in Technical Supplements S-II.

In the final stage of development the two motors and the battery were interconnected so that the ICE acts as the main propulsion unit; during the idling periods it rotates the electric motor which is in that case connected as a generator and charges the battery. In the periods of peak tractive effort, such as initial acceleration and maximum speed, the electric motor is activated to contribute to the required power output. This operational feature reduces maximum requirements for the ICE and allows use of an engine with a low power rating. Current specifications call for an ICE which would provide a peak power output of 40 hp, an additional maximum of 40 hp to be delivered by the electric motor.

This propulsion system has a number of advantages over standard systems. It provides the excellent tractive characteristics of the electric motor, while extending the operating radius well beyond the capacity of the battery since the fuel tank (via the ICE) becomes the determinant. It permits use of a small ICE, resulting in considerable fuel economy and low levels of air pollution. An additional and particularly important feature is that the vehicle will be capable of operating for a certain period of time on the electric power only. This will allow its use in closed areas without problems of ventilation.

Admittedly, this propulsion system is more complicated than the conventional systems; however, it is technically feasible and its reliability is expected to be higher than that of conventional automobiles due to the feature that either of the two motors can work independently if the other one is disabled.

Throughout the design of all mechanical features of the Minicar particular attention has been given to high technical reliability, ruggedness and durability, in addition to feasibility and economy. The steering mechanism selected for Minicar is a rack and pinion steering gear providing a 15-foot turning radius. Drum brakes were utilized with a four-wheel hydraulic service brake

system. All wheels are independently suspended with coil springs and hydraulic shock-absorbers. Conventional equipment has been found most suitable for the vehicle's manual controls, instrumentation, lighting, heating and air conditioning. The Minicar is also to be provided with features for information transfer at vehicle check-out and check-in stations.

Special attention has been given to the safety features of the Minicar. In addition to conventional automobile safety aspects the following are to be provided: energy absorbing fiberglass-foam-steel crash resistant structure, wrap-around protective bumper, foam filled crash bolster around passenger compartment, heavyweight protective frame, fixed seats, inertia-reel mounted seat belts and shoulder harnesses, and collapsible steering wheel.

A number of specific aspects of the vehicle, particularly various components of the power unit, are recommended for further testing and optimization prior to large scale vehicle production. However, the general feasibility of the specially designed vehicle with hybrid power train and other features satisfying Minicar requirements has been verified by the vehicle development and testing completed to date.

#### C. Ways

Minicars would utilize the existing street and highway network, so that no special way facilities are foreseen. This has operational disadvantages, but also represents an extremely important advantage of the MTS with respect to its implementation. At the same time, the possibility of bi-modal and fully automated operation in subsequent stages of development are open.

#### D. Terminals

Terminals for the MTS require study and design in two general areas: (i) the system of terminals, i.e. location and size, and (ii) specific layout and design of individual terminals. A study of the geometric patterns of terminal locations was accomplished in Phase I of the Project. It concluded that a diamond-shaped pattern of terminals provided the optimal geometric layout for a grid pattern of streets with respect to user accessibility and investment and operating cost.

The optimal density and size of terminals were studied by mathematical models in both phases of the Study. The model developed in Phase II was more sophisticated and it included such factors as percentage of trips attracted to the MTS, user walking distance, investment and operating costs of the facilities. Classical optimization was employed to derive the expression for optimal system of terminals, allowing different weighting

values for individual factors. A computer program for computation of the optimal solution was developed, but project time limitations prohibited establishment of the specific optimal system for a test area in Philadelphia. Several areas of extensions of this model are recommended for future research. Technical Supplement S-III provides a more detailed summary of the model and its application.

The study of layout and design of individual terminals conducted within Phase II of the Project consisted principally of developing a general modular concept applicable to all terminals. This concept proposes a basic layout composed of a storage area and a maintenance area with specifically designated parking bays. In initial project implementation leasing of existing garages is envisioned. With larger scale MTS operation specific terminal structures would be constructed where existing parking facilities would not be adequate. Both systems would utilize the modular concept. A summary of the basic criteria developed for the terminal layout is presented in Technical Supplement S-V.

Successful operation of the MTS requires fully automated operational procedures. This can be accomplished by use of a computerized information management system (IS). This system would provide efficient, convenient, reliable, and economical check-in and check-out procedures and furnish in a timely manner all the information and controls necessary for the operation of the MTS. The IS will validate customers and vehicles, release gates, inform operating personnel of processing or maintenance and service requirements, maintain the status of customers and vehicles and perform all billing and cash transaction procedures providing the manager with all necessary operating information.

A preliminary modular IS design was developed consisting of two major component groups-the Remote System and the Central System. The Remote System includes hardware for the terminal and vehicle, for data entry and transmission, and for communications links for exchange of data and control signals with the Central System. The Central System consists of a dedicated on-line command and control computer system and a conventional off-line computer system. This preliminary design not only meets all current MTS requirements, but also provides for incorporation of future technological innovations. In addition, a Minicar reader and wayside terminal were designed, fabricated and evaluated. Early termination of the Project prevented accomplishment of a final detailed IS design as originally planned. While such a final design is essential to Minicar implementation, the preliminary design was of sufficient scope to verify the basic feasibility of the design objectives and functions of the IS. Research in this area of the Project is summarized in Technical Supplement S-IV.

### E. Operational Aspects

The basic operation of MTS was described in the beginning of this Chapter. Several operational aspects which were specifically analyzed in some depth are summarized here.

A major problem of operation between terminals is the redistribution of vehicles. The imbalance in demand for minicars over a 24 hour period coupled with changes in travel patterns will result in surplus vehicles at certain terminals and shortages at others. This aspect was studied within the Project and various solutions conceived as summarized in Technical Supplement S-V. Specific recommendations can be made only after detailed demand and redistribution requirements are obtained for specific systems.

Operations within terminals consist principally of user self-service with check-in and check-out gates tied into the computerized information system. Terminal surveillance is a critical problem and it is discussed with intraterminal operations in Technical Supplement S-V.

Maintenance systems for servicing and repairing the vehicles were studied to considerable extent and are also presented in Technical Supplement V. Vehicle repair requirements were developed in detail and various methods of diagnosis and servicing were investigated. Development of a full scale maintenance system will be based on the principles developed herein, but can be accomplished only after determination of the particular locale and size of MTS to be implemented.

### III. DEMAND PROJECTIONS

#### A. Introduction

The estimation of the future demand for MTS services is essential to the design of the System and to the determination of its economic feasibility. This Chapter briefly summarizes the various efforts made during Phases I and II to arrive at projections of MTS usage.

Two approaches to estimating the future travel demand for an MTS were used in this Study. The first approach relies completely on manifest preferences and on the extrapolation and inference of choice based on a similarity of circumstances. This method is widely used in transportation studies and includes a survey of current travel patterns and modal choices, projection of growth in the region and future trip distribution, modal split, and finally trip assignment. Using this procedure, estimates of demand for an MTS in the Philadelphia CBD were prepared during Phase I of the project. This work is summarized in section B of this chapter; a detailed report is included in reference [R-1]. During Phase II the same techniques were applied to the estimation of demand for an MTS in low income areas as summarized in section C of this chapter. A more detailed report of this work may be found in Technical Supplement VI.

The second approach to estimating future demand relies on direct surveys of carefully selected sample populations and is widely used by market analysts. This study utilized both test surveys of expected user groups and an "MTS User Group Product Clinic" to test reactions of potential users, public officials, the transit, taxi and transportation industry representatives and the communications media. A summary of this work is presented in section D.

#### B. Summary of CBD Demand Estimates

Determination of the potential demand for an MTS in 1975 was an essential part of the feasibility studies performed during Phase I. The work consisted of the selection of a study area, the projection of total travel demand, and modal split analyses for an MTS utilizing synthetic diversion curves. The study area was the Philadelphia CBD since it was considered typical for the older large U.S. cities and the data for it were easily available. The Philadelphia CBD was also considered convenient for possible use as a site for an experiment with the MTS.

Philadelphia is the center of employment and commerce in a large metropolitan region comprising more than 1100 square miles with a population which is growing past the four million mark. Within this region the selected study area encompassed three subareas shown in Figure 2. The Philadelphia CBD is considered as the 'Core' of the study area (designated as 'A'). Those areas immediately to the South, North and West of the CBD ('B', 'C', 'D' and 'E') are considered the 'Fringe of the CBD'. The remaining metropolitan region was designated the 'Study Region' (area 'F' - not shown in Figure 2). Subdivisions of these areas corresponded with those established by the Penn Jersey Transportation Study (PJTS). Analyses of area characteristics and total travel were based on PJTS data for 1960, the base year, and travel projections were for 1975; they represented the only systematic projection of travel needs in the region for 1975.

Demand for the MTS was estimated for two distinct services:

Flat-rate service - the user subscribes for daily use of Minicars for commuting to and from the CBD. A monthly fee includes rent, fuel, repairs, road service, maintenance and cleaning, insurance, and parking in MTS terminals.

Trip-rate service - user pays a mileage charge for each use (see below).

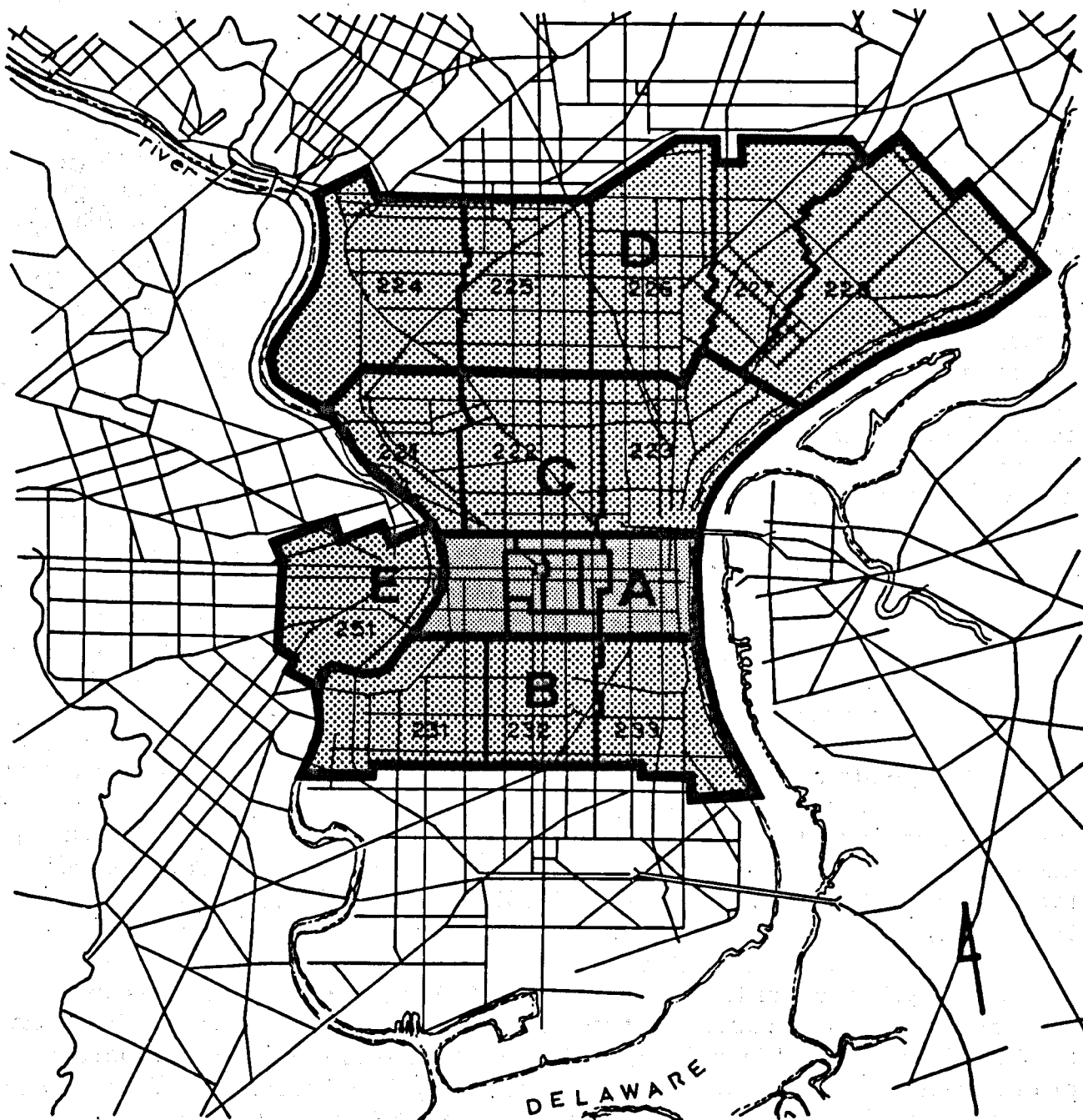
It was estimated that the flat rate service would be able to divert approximately one-half of the 50,000 daily commuter automobile trips to the CBD projected for 1975, implying a need for at least 25,000 Minicars in the Philadelphia MTS fleet.

Daytime use of the Minicars in the CBD as well as some night use were estimated on the basis of a trip rate service as described below. Utilizing the Quandt and Baumol hypothesis that modal choice is based on the relative characteristics of available modes, the study developed a series of diversion curves based on the ratios of total user cost for MTS versus total user cost for other available modes. Alternative sets of assumptions were developed for the following five components of travel cost:

1. Approach Time: (three assumed values)

- (a) zero approach time from and to each Minicar terminal by assuming a great number of terminals;
- (b) maximum approach time from and to each Minicar terminal by assuming only a few major terminals;
- (c) present 'approximate approach time' from and to each Minicar terminal by assuming that most present parking facilities will make space available to an MTS.





AREA A - THE PHILADELPHIA C. B. D.

THE FRINGE AREAS (B, C, D, E,)

AREA B - SOUTH PHILADELPHIA

AREA C - NORTH PHILADELPHIA

AREA D - UPPER NORTH PHILADELPHIA

AREA E - WEST PHILADELPHIA

AREA F - RAILROAD COMMUTERS (NOT SHOWN)

FIGURE 2. TOTAL STUDY AREA - PHASE I

2. Value of User Time: (three assumed values)

- (a) \$1.00 per hour of travel time;
- (b) \$2.00 per hour of travel time;
- (c) \$3.00 per hour of travel time.

3. Parking Cost: (two assumed costs)

(a) \$.50 parking cost per trip for intra CBD trips with both ends in the CBD and \$.25 parking cost per trip for trips with only one end in the CBD;

(b) \$.75 parking cost per trip for intra CBD trips with both ends in the CBD and \$.50 parking cost per trip for trips with only one end in the CBD.

4. Minicar Fare: (two sets of fares)

(a) \$.25 for the first 1.25 miles and \$.25 for each additional mile;

(b) \$.50 for the first 1.25 miles and \$.25 for each additional mile.

5. Auto Trip Cost: (two costs)

(a) Including auto fixed cost of 8.3 per mile  
(6.26 depreciation and 2.04 insurance cost);

(b) Excluding all auto fixed costs.

Utilizing these assumptions and time and distance values for a series of 'representative trips' between selected points in the study area, cost ratios were computed for the alternative values of time. These cost ratios compared the total cost for MTS trips with the total cost for the same trips by bus, taxi and private automobile and with the marginal cost of private automobile travel. The Minicar/Taxi cost ratios were found to favor the Minicar for all values of user time ( $V_u$ ). The same was found for Minicar/Transit ratios except for persons with low values of time (\$1.00/hour) where the higher Minicar fare offsets the time advantage. For the Minicar/Auto cost ratios the Minicar is at a disadvantage for at least half of the representative trips for each value of time. Sensitivity analysis indicated that the cost ratios are very sensitive to both the initial Minicar fare as well as the level and structure of subsequent fares. It was concluded that the fare structure of MTS could be used as a policy tool to change the amount of diversion from present modes.

The cost ratios were utilized to synthesize diversion curves for the daily period (7 a.m. to 7 p.m.) and for the night period (7 p.m. to 7 a.m.). These curves, together with those developed for the low income area analysis may be seen in Figure SVI-6. Application of a modal split analysis, using the diversion curves, to the total projected regional trips from PJTS data resulted in the 1975 MTS demand estimates. It was assumed that certain trips were not susceptible to diversion because of certain characteristics of the trip or the trip-maker (non-drivers, parties of 4 or more people, safety concerns, etc.).

TABLE 1. 1975 DIVERTED TRIPS

Assumptions:

Approach Time: Present 'approximate approach time'

Value of User Time: \$2.00/hour

Parking Cost: \$.75/trip

Minicar Fare: As noted

Auto Trip Cost: Including fixed costs.

	Intra CBD	CBD Fringe	Intra Fringe	Total
Total Trips (Divertible + Non-Divertible)				
Taxi	23,892	17,382	38,116	79,390
Transit	20,462	107,943	100,971	299,376
Auto	34,052	115,832	335,884	485,760
Railroad	-	-	-	111,000
Total	78,406	241,157	474,971	905,526
Divertible Trips				
Taxi	12,535	8,976	19,535	41,046
Transit	8,185	43,178	40,389	91,752
Auto	28,732	97,415	275,303	401,450
Total	49,452	149,299	335,227	534,248
% Diverted from Divertibles - Based on \$.50 Initial Fare				
Taxi	49.8	49.1	47.2	48.4
Transit	27.8	20.7	20.7	21.3
Auto	86.0	35.5	0.0	14.8
Total	67.2	32.1	5.2	18.5
% Diverted from Divertibles - Based on \$.25 Initial Fare				
Taxi	51.9	50.1	49.2	50.2
Transit	38.1	29.8	28.0	29.7
Auto	95.5	81.0	0.0	26.5
Total	74.9	64.5	6.2	28.9

TABLE 2.

## 1975 MINICAR TRIP DEMAND PROJECTIONS BY TIME OF DAY

Assumptions: See Table 1

O.D.	Mode Diverted From	Initial Fare = \$.25			Initial Fare = \$.50		
		7am-7pm	7pm-7am	Total Daily	7am-7pm	7pm-7am	Total Daily
Intra CBD	Taxi	5,674	832	6,506	5,443	799	6,242
	Transit	2,975	143	3,118	2,170	105	2,275
	Auto	24,201	3,238	27,439	21,794	2,916	24,710
	Total	32,850	4,213	37,063	29,407	3,820	33,227
CBD Fringe	Taxi	3,716	783	4,499	3,640	767	4,407
	Transit	11,863	1,004	12,867	8,241	697	8,938
	Auto	65,413	13,493	78,906	28,668	5,914	34,582
	Total	80,992	15,280	96,272	40,549	7,378	47,927
Intra Fringe	Taxi	7,785	1,826	9,611	7,469	1,752	9,221
	Transit	10,031	1,278	11,309	7,416	945	8,361
	Auto	-	-	-	-	-	-
	Total	17,816	3,104	20,920	14,885	2,697	17,582
Sub- Total	Taxi	17,175	3,441	20,616	16,552	3,318	19,870
	Transit	24,869	2,425	27,294	17,827	1,747	19,574
	Auto	89,614	16,731	106,345	50,462	8,830	59,292
	Total	131,658	22,597	154,255	84,841	13,895	98,736
Generated Railroad Linked Trips				9,438			9,438
Total				163,693			108,174

A summary of the total projected trips for 1975, those which are susceptible to diversion to an MTS trip rate service and the proportions of those diverted is summarized in Table 1. The 1975 demand projections by time of day are presented in Table 2. It should be noted that in each table the taxi trips are recorded as vehicle trips and all other trips are presented as person trips. Conversion of these person trips to vehicle trips by dividing person trips by the estimated MTS occupancy resulted in a total demand estimate of approximately 115,000 daily Minicar trips, or a required fleet size of approximately 8000 operating Minicars. A similar procedure produced an estimated demand for 2500 Minicars for the 7 p.m. to 7 a.m. period. Total required fleet size then is based on the night usage, 25,000 commuters (flat rate) plus 2500 for trip-rate users in the CBD for a total of 27-28,000. This would leave about 20,000 cars available during the day for application to fleet use in the CBD (post office, delivery services, etc.) or for reducing the daily utilization rate, providing higher reliability of service.

The results of this study showed that the fare structure tested was not adequate because of the excessive diversion from transit which it would cause. Further research was clearly indicated. Another conclusion was that because of the high diversion from transit and taxis and lack of diversion from automobiles for intra-fringe trips (see Table 1), these trips should be ignored in planning an MTS for CBD. Alternatively, if for social reasons or some other objectives introduction of an MTS in the areas surrounding the CBD is considered desirable, a special operation and fare structure must be devised. The extensive latent demand of the population groups in these areas must also be taken into account. Consideration of these problems was undertaken in Phase II since the CBD fringe areas include many of the city's low income areas. This work is summarized in the following section.

### C. Summary of Low Income Area Demand Estimates

The basic procedures used to produce the CBD demand estimates were also applied in the analysis of low income area demand projections and economic feasibility analysis. This section summarizes the modifications required and presents the conclusions of that analysis. A detailed summary of the work is given in Technical Supplement S-VI.

The regional boundaries of the low income area were determined by comparison of the incomes, employment rates and educational attainment levels of the various Penn-Jersey Data Collection Districts. The resulting 'formal study area' is shown in Figure SVI-2. Because of the

dispersion of employment, shopping and recreation activities throughout the region it was necessary to utilize a number of other study areas, all having as a common core the low income fringe around the CBD.

The Phase I research indicated that it was necessary to examine an MTS with a modified fare structure and payment methods, including provisions for the sharing of cash fares by users. The services examined include:

1. Extended Trip-Rate Service. This is an arial extension of the regular trip rate service, fully integrated with the CBD service but with cash fares, variable fare charges for different terminals and the shared-fare provision.
2. Reverse Commuting Service. This service is similar to the flat rate commuter service but oriented for the inner city resident with a suburban job and with a fare structure other than the monthly credit system. No low income area terminals are required for this particular service.
3. Limited Trip-Rate Service. This evening and weekend service would supplement the reverse commuting service possibly with hourly leasing plus a small mileage charge to stimulate use. Terminals would be located in low income areas.
4. Additional MTS Suburban Services. The extended services decribed above imply the introduction of a number of complementary suburban-based services to increase vehicle usage.

Combinations of these services were also analyzed.

The procedure for estimating MTS demand in low income areas was similar to the modal split analysis performed in Phase I. The major difference was the increased number of sets of travel parameters (Minicar fare, value of user time, terminal spacing and parking cost) examined to produce cost ratios and synthetic diversion curves. Representative sets are shown in Table SVI-3 and the resulting diversion curves are presented in Figure SVI-6.

Demand estimates for the various services are presented in Figures SVI-7, 8, 9 and 10 and summarized in Table SVI-5 (for  $V_t = \$2.00/\text{hour}$ ). Latent demand in low income areas was estimated to be minimal unless the Minicar fares are made considerably cheaper than those examined in this study and/or the incomes in those areas increase. The 'range' of estimated 1975 daily Minicar trips based on the total low income area manifest and latent demand was found to be from 118,000 to 364,000 trips per day. This range

of trips is a function of the operating conditions, particularly MTS fares. The total demand estimates were further based on the assumption that the MTS would be available to all potential users and would provide a combination of trip rate, reverse commuting and daytime suburban services.

Evaluation of the proposed MTS indicated that adjustable fare rates, variable terminal entry and exit charges and mileage and time charges would be desirable.

Based on the analyses in this study it has been determined that in order to maximize probability of success, an MTS which should serve low income areas should have the following characteristics:

(1) A system of terminals approximately 1/3 miles apart within the low income areas that provide for:

(a) Flat and Trip-Rate Services within and around the low income areas during the weekdays;

(b) Reverse Commuting Services from the low income areas to a set of selected suburban districts appropriately located and including appropriate job concentration; and

(c) Evening and weekend services within and around the low income areas.

(2) A system of terminals in a number of suburban areas (approximately a dozen appear probable at this time) that are located within a distance of less than 12 miles from the Philadelphia CBD and that include important concentrations of jobs suitable to the skill levels of low income (unskilled or semiskilled) individuals. This set of terminals will provide the following services:

(a) Discharge and pick-up services for vehicles used for the Reverse Commuting Service of low income areas; and

(b) Daytime (10:00 a.m. to 4:00 p.m.) suburban services for suburban housewives and others primarily for shopping, recreation, medical and school trips.

Although the study indicates that all these system characteristics are desirable, a rigorous economic feasibility study for such a system could not be done due to lack of detailed cost information on the initiation and operation of the system. Additional research would be needed to develop more precise cost estimates so that a reliable feasibility study could be performed.

## D. Market Segmentation Analysis

### 1. Objectives

The market segmentation analysis attempted to determine the number and types of potential customers for the MTS and to measure the response of these customers to changes in key marketing variables. This information was desired to assist in:

- (a) Formulating marketing strategies by market segment;
- (b) Complementing existing demand estimates;
- (c) Improving the design of the MTS.

From a methodological viewpoint, the objectives were to study and compare the usefulness of alternative techniques for estimating demand. These techniques fall into three major categories:

- (a) Subjective analyses (what demand for the MTS do experts foresee?);
- (b) Attitude surveys (how many people say they will use the MTS?);
- (c) Small scale experimentation (how many people, out of a prespecified sample, actually do use the MTS?).

Each class of techniques was to be used to obtain estimates for each major consumer segment. No experimentation, however, had been planned for the Phase II of the study.

### 2. Work Completed

The major tasks which were carried out under the market segmentation analysis include the following activities:

(a) A conceptual framework was developed. This framework, described in Reference [T-10], served as the basis for most of the research done on market segmentation.

(b) A Monte Carlo simulation program was developed to allow for estimates of the distribution of demand by market segment to be translated into an estimate of the distribution of total demand. In other words, this program provides not only an estimate of expected demand but also of the confidence which may be placed on the demand estimate. In addition, the program assists in identifying which segments contribute most to the uncertainty in the estimate of the total market.



The program, described in [P-4], would work as follows: an expert (possibly a member of the Minicar study team) would provide subjective estimates for the mean of each market segment and would also express how confident he was of each estimate. The program would then translate these segment-by-segment estimates into an estimate of the total demand and an aggregate measure of confidence. The process could be repeated with different experts or even with different teams of experts.

(c) A subjective analysis of consumer demand for the MTS was carried out for what was expected to be the population segment with the greatest demand. This analysis is described in Reference [T-12]. Particular attention was paid to assessing the cost of alternatives to the Minicar, including driving a new or used car.

(d) Attitude surveys were used to estimate demand by market segment. The basic strategy might be described as "eclectic research." Rather than conducting one large scale survey, the problem was attacked by a series of smaller independent surveys. It was felt that one of the best ways to assess the confidence which might be placed in the surveys was to examine the agreement among these different survey approaches (the test of construct validity). In general, in these surveys people were asked about their travel habits, whether they thought they would use the MTS (and at what price), and what they thought about the design of the MTS. Information was also obtained about demographic characteristics.

There were four basic studies. Three of the studies [T-14, p.3 and P-6] were completed. Work was in process on the fourth study which was known as the "MTS User Group Product Clinic," at the time that the MTS study was terminated. The objectives of this study were outlined in Reference [T-11]. A brief description of the results from the User Group Product Clinic is presented in Reference [T-13]. Usable data were collected from 176 visitors to the product clinic and also from about 1700 people who were surveyed by mail. Beyond a simple tabulation of some of the results, there was little analysis of the product clinic data.

(e) Some of the data from the attitude surveys were analyzed by both multiple regression and multi-variate cross-classification. There were two objectives of this study. First, there was some interest in the methodological question of which technique offers the best way to analyze the data. These results would have been useful in the additional analyses which had been planned. And, second, there was the question as to why did people desire to use the Minicar. Were there any characteristics which would help us to distinguish users from non-users? This knowledge of potential consumers would have been useful in designing a marketing strategy. This effort is summarized in [P-5].

### 3. Conclusions

The major conclusions reached in the market segmentation study were:

(a) Demand one year after implementation for the MTS flat-rate service would be about 25,000 vehicles, subject to the system performing according to the description current in June 1969 and an approximate rental of \$90 per month. This estimate was based on subjective analyses and on the analysis of approximately 500 respondents to attitude surveys. The 95% confidence limits for this demand estimate, also derived subjectively, were from 10,000 to 50,000 vehicles. Further analysis of this sample of respondents, as well as the analysis of data from approximately 300 additional respondents could have reduced this uncertainty.

(b) The MTS flat-rate service is expected to draw more heavily from commuters to the CBD who currently use public transit than from current auto users. This implies that the net effects of the MTS upon traffic land, land use, and air pollution might be detrimental. This conclusion was originally reached in the study by Davis [P-3]. That study indicated that the MTS would draw more heavily in percentage terms from people who drive than from people who currently go to work by mass transit (44% drivers vs. 33% transit riders). However, the latter group is so much larger (68,000 transit riders vs. 26,000 drivers) that the number of people diverted from mass transit would be greater than the number diverted from autos. [See P-3, p.6].

Additional studies indicated that much uncertainty exists in the estimated proportion of people diverted. For example, it was estimated that the proportion diverted from auto would be larger relative to that diverted from mass transit (49% vs. 19%) if the MTS were to be priced at \$75/mo. Furthermore the diversion becomes even more favorable as the price is increased (36% vs. 9% if \$100/mo.). However, the results from the mail and interview studies associated with the product clinic were more in line with those from the Davis study (roughly 41% from autos vs. 28% from transit). Also, a re-analysis of data from Finkel et al [T-14] showed little difference in the proportion drawn from mass transit vs. auto although the sample size in this study was very small.

No formal integration of the above studies was carried out. The studies were integrated in a crude manner by providing subjective inputs to the computer model to estimate demand distributions. These estimates indicated that the number of commuters diverted from mass transit exceeded those drawn from autos by about 30%. (See [P-4, p. 88] for raw supporting data.)

Consequently, the attitude studies did not support the idea that the development of the MTS with the pricing schedule as assumed for purposes of this study would be in the public interest and that it should be supported by government funding. Of course, there may be other arguments for such support (e.g. environmental, special social purposes, etc.) and other conditions (e.g. better coordination among parking rates for private automobiles, Minicar rates and transit fares) which would result in a different diversion pattern and make the System much more desirable.

(c) The present evidence strongly supports the use of mail questionnaires as the most cost/effective data gathering method for MTS public preference studies. Mail questionnaires provided similar results to the product clinic presentation, but at 1/10 the cost and with less nonresponse. This finding is discussed in [P-1]. This conclusion would be useful in designing further studies for the Philadelphia area and also for examination of demand in other cities.

(d) There was only very modest success in finding characteristics which were useful in distinguishing between people who said they would be likely to use the MTS flat rate service and those who said they would be unlikely to use the MTS. This conclusion is based on Reference [P-5]. The major reason for this appears to be that commuting was not the most common reason stated by people as to why they would use the flat rate service. This conclusion was drawn from the Product Clinic Study (T-13). The most popular reasons stated were "business travel" and "shopping in downtown area." However, again there is much uncertainty about this conclusion. The results of the survey should be adjusted by considering only those likely to use flat rate service. Another uncertainty is also how representative the Product Clinic results are of the Philadelphia market .

One implication from the preceding paragraph is that adequate information on which to develop a marketing strategy for each segment of potential users is not yet available.

#### IV. ECONOMIC, ORGANIZATIONAL AND LEGAL ASPECTS

Economic feasibility and a viable legal and organizational structure of an MTS are important elements in the decisions about eventual implementation of the system. Economic and legal aspects are in turn closely related to decisions about the physical and operational aspects of the system. For example, the types of service to be offered and the form of the contract required to use a Minicar have strong bearing on legal requirements. Likewise precise revenue estimates and cost data require a completely specified physical system, a knowledge of the type of operating authority, the amount of taxes and accurate demand projections.

Research within this study included all of these aspects, i.e. economic, legal and organizational aspects of the MTS, paralleling the studies of demand for Minicar and the system's physical aspects. These studies were performed simultaneously. Although they were based on the common initial definition of the MTS, some of the initial assumptions changed so that it would have been necessary to perform another round of studies to coordinate analyses in individual areas. This final round was not completed prior to the Project termination. The feasibility study which was conducted utilized the best available data and can be regarded as a reasonable estimate of the MTS's economic success. However, a decision to proceed with implementation of an MTS will require the use of more precise data inputs for the simulation model. Some of the important data for this study would be provided by an actual small-size System experiment.

Research of economic aspects during Phase II of the Project extended the feasibility analysis begun in Phase I (reported in reference[R-1]). The latter work is briefly summarized below in Section A, while a detailed summary appears in Technical Supplement S-VII.

Research into the legal and organizational aspects of the MTS during Phase II of the Project concentrated on the requirements for an experimental system operating in the Philadelphia region, with the expectation that work on a full scale MTS would be under-taken during the following year of the Project. A detailed summary of the legal analysis is presented in Technical Supplement S-VIII. The conclusions from this Supplement have been extracted for this summary as Section B.

##### A. Economic Aspects

The study of MTS economic feasibility begun during Phase I of the Project was extended during Phase II through the construction and application of a digital computer simulation model. This approach facilitated

sensitivity studies of the key revenue and cost assumptions. The developed simulation technique allows rapid recalculation of the entire feasibility analysis as improved cost and revenue estimates become available in the future. The model was further designed to provide a means for efficient financial evaluation of an experimental system's performance.

An optimization study was carried out using two main variables: the rate of introduction of additional vehicles into the System and the maximum steady-state number of Minicars. Cost and revenue assumptions, and the resulting data, were based on 1968 estimates which are presented in detail in Technical Supplement S-VII. The present discounted value of a 48 quarter cash flow was used as the optimization criterion.

The demand projections and cost and revenue assumptions utilized indicate that an optimum system would have 5,800 vehicles with an estimated present discounted value of \$27 million. The rate of vehicle introduction was 225 cars/quarter. Capital investment requirements for this system amounted to about \$7 million.

The sensitivity of the system to the fare level and structure, vehicle capital cost and vehicle operating cost was analyzed with reference to cash flow and equity capital. The time required for the System to achieve positive cash flow and positive equity capital is, as Figure S VII - 4 illustrates, highly sensitive to the level of fares charged, particularly to the level of trip-rate fares. The System also appears sensitive to Minicar vehicle first costs but shows relative insensitivity to vehicle operating costs.

No attempt has been made to perform a quantitative social cost-benefit analysis of the MTS. Conceivably, the same cash flow framework could be used if one were willing to ascribe dollar values to social costs and benefits. Since it is expected that for a carefully planned and optimally employed MTS, social benefits outweigh social costs, it is likely that the optimal System size would increase when these social considerations are taken into account.

The conclusion of the feasibility study is that an MTS, based on the assumptions used in the model, is economically feasible. However, it would require a large capital investment - probably too large for any single private entrepreneur or private institution to undertake alone. The results of the sensitivity analysis indicate the critical nature of demand and revenue assumptions. Since these assumptions have some inherent uncertainties, they must be carefully tested and re-evaluated during the experimental phase of the System.

As mentioned above, there now exists a computer model of the MTS which may be used as powerful analytical tool to perform sensitivity and feasibility analyses. Changes in cost and revenue assumptions can easily be incorporated into the model at a fraction of the previous cost in man-hours. If so desired, the model can be further expanded to include more sophisticated design. For example, it would be interesting to analyze the effect of various pricing policies on the number of trips diverted from other modes of transportation; to include vehicle redistribution costs into the general System model; to allow the approach time to terminals to vary with the number of terminals; and, to attempt to quantify some of the social costs and benefits.

### B. Legal and Organizational Aspects

Emphasis of the Phase II research was on the problems surrounding the establishment of an experimental MTS in the Philadelphia region. Consequently, the work so far completed produced the following general conclusions limited to the tri-state area of Pennsylvania, New Jersey and Delaware.

#### 1. Government Control of the MTS

If Southeastern Pennsylvania Transportation Authority operates the MTS, no state or federal regulatory agency aside from SEPTA itself has jurisdiction. If the MTS is privately owned, the Pennsylvania Public Utility Commission may have jurisdiction; and since there is uncertainty, a private operator would be well advised to apply to the Commission before starting operations.

#### 2. Insurance Requirements: Property Loss and Personal Injury Liabilities of the MTS

The MTS will have to insure its customers as well as itself in order to satisfy the Pennsylvania, New Jersey and Delaware financial responsibility requirements. For if its customers are not liberally insured, in actions arising out of the negligence of a customer the juries will sympathize with the injured plaintiff, and seeing a large organization which can spread the cost of liability, will make the MTS jointly liable with the customer. Such joint liability can be imposed on the MTS when it has negligently entrusted its vehicle to an incompetent, and possibly when it has failed to prevent withdrawal by an unauthorized person at its terminals. The insurance carrier who insures MTS for its own liability is bound to consider the fact that judgements against large corporations tend to run considerably higher than against individuals. It seems likely, therefore, that the carrier will demand as a condition of coverage that MTS take every reasonable precaution to avoid judgements against itself. Thus the carrier may demand that MTS establish procedures at its terminals which are reasonably capable of determining the competence of the customer before he withdraws the vehicle--possibly, even, procedures

capable of determining whether the user is an authorized card holder.

In addition, the MTS can be liable individually if it provides a defective vehicle to a competent driver. The inspection procedures which the MTS utilizes therefore must be thorough and frequent. If the MTS is designated as a common carrier or is operated by SEPTA, these procedures must allow for a few mistakes, as the standard of care which the courts apply to a common carrier is higher than that applied to an unregulated rent-a-car business.

### 3. Potential Criminal and Quasi-Criminal Liabilities of the MTS and its Officers

Five offenses provided under varying combinations of Pennsylvania, New Jersey and Delaware law have been identified as having special applicability to the MTS: (i) permitting an unregistered vehicle to be on the public highways; (ii) equipment violations; (iii) permitting an intoxicated person to operate a Minicar; (iv) permitting a minor or anyone without a valid license to operate a Minicar; and (v) failing to keep records of vehicles leased. Regarding these offenses as a group, it is more likely that the MTS can be convicted of violating them as a corporation than that individual MTS officers can be reached: it is more likely that the MTS will be tried for offenses prescribed by Pennsylvania law than those prescribed by Delaware or New Jersey law (unless rental terminals are established in those states); it is unlikely that any penalties besides relatively small fines will be imposed for any violations; and it is unlikely that any convictions will take place if the MTS is careful to screen its vehicles and customers each time they exit from an MTS terminal.

In determining whether to omit expensive or inconvenient precautions at the terminals and risk the consequences, however, the MTS should be concerned about criminal and quasi-criminal liability arising out of its operations. Numerous violations may lead to revocation of MTS licenses. In addition, the possibility of imprisonment for individual MTS officers, though small, is not inconsiderable, especially if there are numerous instances of Minicars being entrusted to intoxicated persons who cause severe personal and property damage. And needless to add, public confidence in, and acceptance of, the MTS will be greatly undermined by even a few minor criminal proceedings against the System.

## V. EXPECTED MTS IMPACT

### A. Introduction

The impact of transportation systems on economic, social and other aspects of an area has been the subject of numerous studies. The consensus of the rather voluminous literature on this topic is, however, that estimation of this impact for existing systems is a complex problem due to the many intangible effects involved and due to the fact that "control situations" cannot be organized. Prediction of the impact of an entirely new system is, of course, even more complex and difficult. Experience indicates that such studies have shown a greater tendency to underestimate than to overestimate the long-range impact of transportation, whether it is positive or negative.

This Chapter summarizes results of considerable work in this Study which was performed to estimate the impact of the MTS. Most of this work was performed in Phase I of the Study and reported in [ R-1, Chapters V and VI ]. Those findings are briefly summarized here and supplemented by the results of impact studies performed in Phase II.

### B. Availability of an MTS

Availability of an MTS in an urban area would result in an increased choice of transportation modes for the population. It is particularly important that the persons capable of driving who presently cannot afford an automobile would have available a system of individual transportation on which they could afford some incidental trips. With an MTS some trips could be performed more conveniently and some new ones could be undertaken. Trips by Minicars would cause lower user "cost" (the term is used here broadly, incorporating not only monetary cost of travel) since travelers would choose Minicars only when they are "cheaper" than other modes. This would result in increased mobility of the urban population with all its positive consequences for the population and the city in terms of economic, social and other improvements.

Several aspects of the expected MTS impact depend greatly on the pattern of its use: from which modes would Minicar trips be diverted and how many new trips would be generated. It will be shown that the substitution of small rented vehicles for conventional privately owned ones (diversion from autos to Minicars) would have a number of significant positive effects on users and the city; diversion from public transportation might, however, create serious problems.



### C. Diversion from Private Automobiles

The change of certain trips from private automobiles to Minicars would create benefits to the users as well as the city. These effects are summarized here.

#### 1. Parking

The Report on Phase I, referenced above, showed that the MTS would bring considerable benefits to the users as well as to the city in terms of: area required for parking, simpler terminal operations, convenience to the users, and impact on curb parking. While all of these impacts would be positive, the first one - reduced areas required for parking - would be by far the most significant.

It was shown that due to fleet operation, as compared with private ownership of automobiles, capacity of parking garages and lots could be increased by a factor of approximately 1.6; since Minicars are smaller than conventional cars the capacity could be increased by an additional factor of 2.0 - 2.3, so that the overall improvement would amount to a factor of 3.2 - 3.6. This improvement would be even more significant for parking facilities specially designed for Minicars in which complete automation would allow full utilization of parking area.

Additional studies in Phase II have shown that maintenance operations in the terminals as currently conceived, would require more space than such areas in the existing garages, so that the increase factors quoted above would be lower. However, the analysis which derived the above factors did not take into account the much higher turnover which Minicars would have as compared with privately owned automobiles. If this turnover were introduced in the study, the factor might be increased considerably and more than cancel the impact of additional area requirements for maintenance in terminals. The intention was to include this aspect by analyzing Minicar space requirements per trip rather than per vehicle. It is considered that this problem is not only significant for the MTS, but also for several other related systems. The problem was formulated, but the research was not performed within this study.

#### 2. Traffic Flow

Studies of the impact of substitution of Minicars for conventional cars on traffic flow, performed in Phase I and reported in [ R-1 ], resulted in the following significant findings:

(1) Capacity of intersections clear of congestion, but with saturated queues, can be increased by 6 to 16% if the length of vehicles is reduced by 50%, i.e. if Minicars are substituted for conventional automobiles.

(ii) The impact of Minicars on highway capacity would be positive, although small under normal conditions, i.e. in free flow; as the speed decreases, the impact of reduced vehicle length increases.

(iii) Street capacity would also be positively affected by introduction of Minicars. The impact would be inversely proportional to the speed of traffic. In narrow streets with congested conditions the increase in traffic flow can be in the range of 30 to 50% and exceptionally even as high as 70% for the case that Minicars are substituted for all conventional automobiles.

These percentages may be deceiving since in congested conditions the speeds are very low so that an increase of 2 - 4 mph may represent 50 or 70%. However, an increase in speed of that relative magnitude under such conditions results in a drastic reduction of travel times and an even greater reduction of vehicle queues.

(iv) The impact of different types of vehicles on traffic congestion can be expressed by the street occupancy\* which that vehicle requires as compared with the street occupancy of a passenger automobile. This factor is designated as the p.c.u. (passenger car unit) factor.

It has been estimated that the p.c.u. for a Minicar at a speed of 15 m/h (average free flow speed in central urban areas) is 0.85. Taking into account different vehicle occupancies, the impact of the shift of one passenger from different modes to Minicars would be as follows [ R-5 ]

<u>Shift from:</u>	<u>Change in p.c.u.</u>
Private auto	-0.12
Taxi	-0.12
Bus	+0.66
Pedestrian, rapid transit	+0.68

Consequently, the shift of each person from a private automobile to a Minicar under typical urban conditions would reduce the congestion caused by that person by approximately 12%.

(v) The impact of Minicars on queuing and travel time would, however, be even more significant than their impact on congestion. It is shown in Supplement XI that in a given situation of congested traffic in which conventional

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\* Street occupancy of a vehicle is that area of the street which the vehicle requires for safe operation; it is a function of vehicle's size, characteristics and speed.

automobiles would experience an average delay of 11.7 minutes, such a queue of Minicars would cause an average delay of only 5.5 minutes and would affect 52% fewer vehicles.

This estimated impact of Minicars is very significant since it would result in an increased utilization of the existing facilities, reducing investment requirements for the city and increasing the level of service for the users.

### 3. Other Effects

a. Physical Side Effects. Due to a specially designed propulsion system Minicar emissions will be substantially lower than the emissions of conventional automobiles. If the maximum noise level standards are established for the fleet of Minicars, they will also cause less noise than average conventional automobiles. These reductions of engine emissions and noise would be appreciable in the areas of heavy traffic congestion, which are usually also the locations at which the greatest number of persons is affected by them.

b. User costs. Since only those persons who find Minicars to be either cheaper or more convenient than their present mode of transportation would use Minicars, they would benefit from the change either through reduced costs or through other advantages. Consequently, an MTS would cause user cost savings. The magnitude of these savings cannot, however, be estimated with any acceptable degree of reliability.

c. Travel patterns. The "disposability" of Minicars eliminates the interdependency of consecutive trips, which is a negative feature of private automobiles. Frequently, a person must drive his car instead of riding transit into the city because of a trip he has to make during the day, which can be performed only by automobile. This would not be necessary if Minicars were available. They would make it possible to perform multi-ended trips by several different systems, so that users could choose the optimum system for each portion of their trips.

### D. Diversion from Other Modes

Diversion of trips from all other modes, except taxis, to Minicars would be far less favorable than diversion of trips from private automobiles. The impacts are summarized below.

## 1. Taxis

Diversion of taxi trips to Minicars which may in some cities be appreciable, (for diversion estimates see Chapter III) would have the same physical effects as diversion from private automobiles, except that there would be no benefits in parking area savings.

In those cities in which taxi service is now inadequate Minicars would be desirable since they would satisfy a latent demand which is presently not being served. However, diversion from taxis may be negative if it results in a significant deterioration of taxi service, since even with the introduction of Minicars, taxis would continue to perform the very essential role of serving all those persons who require individual transportation and either cannot or do not want to drive.

## 2. Public Transportation

Diversion of trips from public transportation to Minicars would be highly undesirable for two major reasons. First, it would increase street congestion: figures on the impact of diversion from different modes indicate that each diversion of one passenger from public transportation (as well as a newly generated vehicular trip) would require diversion of approximately 5 passengers from private automobiles to compensate for the increased congestion. Second, reduction of public transport passengers would result in reduction of its level of service, negatively affecting the city and transit users, particularly the low income population which depends on it most.

On the other hand, the Minicar may in many cases serve for collection-distribution of public transport passengers. This would be, for example, the case in many suburban areas. By performing this function, Minicars could cause diversion of trips from automobiles to public transport.

How significant each of the two impacts would be depends on both the conditions in a given area and the planning and regulation of the MTS. Conclusions of the demand projections for the Philadelphia CBD performed in Phase I indicate that this diversion should not be very significant (see Section III-B); a marketing analysis of the demand in Phase II (Section III-D) differs somewhat in its findings since it concludes that the diversion pattern would be different and diversion from transit might be appreciable. A conclusion of demand projections for low income areas is that a considerable portion of the demand for Minicars in these areas would be diverted from public transit. Since all indications are that diversion from transit would heavily depend on the rates charged for Minicar trips, this diversion can be controlled by careful planning of those rates. This factor clearly indicates

the need for strict regulation of the MTS, particularly if it is operated as a private organization.

#### E. Conclusions

The above analysis indicates that the impact of MTS greatly depends on the pattern of diversion of trips to that System. Diversion of trips from private automobiles to Minicars would clearly benefit the users and the city in a number of ways. Diversion from public transportation would be undesirable for several reasons.

Trip diversion patterns estimated in demand projections for the Philadelphia CBD (by Dr. Tomazinis in Chapter III), would have a significant diversion from private automobiles. However diversion from transit would also be appreciable and probably more than offset the benefits of diversion from automobiles. Conclusions of studies performed through market segmentation analysis (by Dr. Armstrong, also in Chapter III) also caution against these effects. Consequently, the diversion pattern would have to be changed by applying a different MTS rate structure (particularly higher initial step) than the one which was used for those estimates; this is entirely feasible, although a reevaluation of demand estimates would have to be done for the new rate schedule.

Since at the present time various transportation rates are often virtually uncoordinated and socially undesirable (good examples are degressive parking rates, i.e. lower cost per hour for long than for short-term parking flat transit fares, etc.), it would be most desirable to establish a single, coordinated policy for all modes of transportation in a city, including the MTS. Such a coordination has brought extremely good results in the cities which have introduced it (e.g. Hamburg, Amsterdam and London).

It is concluded that the direct and indirect impact of introduction of an MTS on urban transportation would be positive and of appreciable magnitude if the System were planned carefully and regulated in coordination with other transportation policies to achieve a desirable pattern of diversion of trips to it. This control appears feasible although exact measures for a given set of conditions would have to be determined through actual experimentation.

## VI. CONCEPTUAL AND FUNCTIONAL ANALYSIS OF THE MTS

### A. Analysis of the MTS Concept

Each one of the two unique concepts of the Minicar Transit System—specially designed vehicles for urban service and fleet operation—gives the System, in comparison with other urban transportation systems, certain advantages, as well as drawbacks and limitations. At a risk of some repetition it appears worthwhile to review them briefly.

#### 1. Advantages

MTS combines the advantage of individual travel (personal routing and personal schedule) of the private automobile with the availability of common carriers: users can travel without owning a vehicle.

Both MTS concepts (special vehicle and fleet operation) contribute, in varying degrees, to the benefits which the system potentially offers. For example, lower parking space requirements result from both special vehicle design and fleet operation. Both concepts also contribute to the economic advantages of the System. The specially designed vehicle provides for maximum reliability and minimum maintenance costs; shared use reduces the cost per trip.

In the long run the high flexibility of Minicar use due to the ease of renting and dropping them off at any time is likely to permit freer adjustment of traffic flow to urban conditions. If, for example, traffic flow reaches capacity and congestion occurs, it is likely that some of the drivers will decide to drop their Minicars off at the nearest terminal (which option they do not have if they are using their own automobiles), and use another mode. A greater number of combinations of modes can be made for every trip, so that the congestion level at which the tolerance (limit) of drivers is reached and they begin to look for alternate modes or times of travel is likely to be lower than at present. Thus it may be expected that in general, the traffic situation would improve due to the MTS characteristics.

Easy implementation of the MTS due to the compatibility of Minicars with the street network is one of the major advantages of the System. The System does, however, require a certain scale in order to provide its maximum efficiency; while it is small, the number of terminals is limited and its utilization is therefore also limited. It is possible, however, to make a small-scale experiment with an MTS and still derive from conclusions about the full-scale system. The experiment must be organized with a selected,

controlled group of users for certain types of trips only.

MTS also offers a number of evolutionary options. If the concept of renting proves successful, MTS operation may be improved by providing separate lanes in the existing streets, separate entire streets, or in a further stage special guideways leading to bi-modal operation and eventual full automation.

## 2. Limitations and disadvantages

The same basic characteristics of the MTS create certain limitations. The major deficiency of the System is that it has limited availability. Like private automobiles it is limited to use by drivers only (at least as long as Minicars are operated manually, as presently foreseen), like public transportation, it is available only at certain points (terminals).

Operationally the MTS has limitations similar to those of the private automobile system: low capacity, low reliability due to congestion and inclement weather, low safety compared with public transport, etc. Yet, in most of these characteristics it is somewhat superior to the system of private conventional automobiles, as the comparisons of traffic flows with the two types of vehicles and of other aspects indicate (see, for example, Chapter V).

Opposed to the cost advantages of the MTS discussed above, its cost disadvantages are that the System must provide for its overhead, for special facilities (maintenance, information system, etc.) and for an excess in vehicle supply to achieve the required reliability of finding a vehicle at any terminal. Many of these items will involve considerably lower total cost than a corresponding number of private automobiles would require (standardized vehicles, maintenance, etc.), but the costs of private automobiles are absorbed with less awareness by the owners than when they are directly reflected in the cost of each trip.

### B. Analysis of CBD Transportation

To estimate the potential role of an MTS in central urban areas, it was necessary to obtain rather detailed information on existing traffic conditions in these areas, and then make a comparative analysis of different transportation systems which are, or could be, used in them. Since it is difficult to make an analysis of this type for a hypothetical city, and, on the other hand, the detailed data about traffic conditions in different cities are difficult to obtain, it was decided to use the Philadelphia CBD for a case study as typical of the CBD's in large U.S. cities.

A rather detailed study of traffic conditions in the Philadelphia CBD, reported in Supplement S-IX, has concluded that the level of automobile and surface transit service in that area is generally very low. It is significant however that the problem is due not so much to high volumes of traffic as to inadequate traffic regulation (e.g. antiquated signal system) and lack of enforcement, resulting in extensive illegal parking, loading and other activities, which seriously impede traffic and prevent an efficient utilization of streets.

In this situation, which is, unfortunately, typical for many U.S. cities improved traffic regulation and enforcement would probably be a more cost-effective improvement than the introduction of new systems which would also be impeded by the existing conditions. The fact remains however that the substitution of Minicars for conventional automobiles would represent an improvement even if that system's potential could not be developed because impedances. In addition to traffic flow improvements on MTS should improve off-street parking conditions and make enforcement of parking regulations easier.

To determine the types of trips which an MTS would best serve and to define the potential role of the System in Urban Transportation, a comparative analysis of different systems which could be used to provide a "ubiquitous mobility" in CBD was made. That analysis is summarized in, Technical Supplement S-XII.

All potential systems for short-haul transportation were classified into eight parametrically defined system categories, which were then evaluated on the basis of 14 criteria concerning the users, the system operator and the city. The analysis indicates that, as one would logically expect, a public transport system on private right-of-way, providing an adequate area coverage, would be the most efficient, although a very expensive system. The analysis also indicates that four systems from three different parametric categories have considerable potential which could be utilized if relatively small investments were made. All these systems would improve utilization of existing facilities. The four systems are: walking, existing public transportation, MTS, and a Minibus System (defined below). Each of those systems should be studied in-depth for many cities. Here only general comments about each system will be summarized.

Much of urban development in the last 2-3 decades has been such that it has discouraged walking even in central urban areas where its efficiency has been well known. Improvement of both, pedestrian facilities and the whole urban environment, could increase the attractiveness of this travel for short trips.



Existing public transportation is also greatly underutilized. Flat fare, used in most cities, is prohibitively high for short trips so that, despite adequate frequency and network coverage in many cities (Philadelphia is an excellent example), transit does not serve short haul movements in the CBD. Special fares for short trips, modern fare collection methods and improved information about transit services would be the basic steps toward increased utilization of transit, thereby reducing street congestion.

A comparative analysis of travel times for several types of CBD trips by different modes has shown that Minicars would offer the shortest travel time of all modes for those trips longer than 1 - 1.5 miles which do not follow rapid transit lines. Assuming a large MTS (high density of terminals), Minicars would offer shorter time than private automobiles for most trips.

A rather crude analysis of a Minibus System has produced some interesting results which are presented in Technical Supplement S-XII. The Minibus System consists of a series of minibus lines (one on each street) providing total coverage for the CBD, a scheme never yet applied to any city. Compared to an MTS such a Minibus System in the Philadelphia CBD, for examples would provide:

- a. Better area coverage, but within CBD only, no service outside of it;
- b. Service limited to the day hours;
- c. Transportation for everybody (not drivers only);
- d. Lower comfort of ride (no privacy);
- e. Considerably lower fare (20-25¢ vs. 50¢-\$1.00);
- f. Lower travel speed, but also lower terminal times;
- g. Comparable convenience;
- h. Lower social cost (congestion, etc.);
- i. Higher safety and reliability.

This clearly indicates that such a Minibus System may have potential in some cities and deserves careful attention.

It is important to point out here that these conclusions about underutilized potential of walking, transit and Minibus Systems do not mean that there is no place for Minicars in the central urban area. Each one of these four systems potentially has a different role. Walking is for example, nearly always optimal for trips up to 1000-1500 feet, but its improvement does not obviate the need for transit. Minicars would offer a different "cost/level of service package" than Minibuses, although some competition would certainly exist. If both were introduced in the same city, a careful analysis of the effect of one on demand for the other should be undertaken.

A well planned MTS and a Minibus System could, however, create conditions which would allow suppression of private automobile use and eventually its elimination from certain congested urban areas, since the two systems would provide an adequate substitute for most trip types presently served by private automobiles.

It is concluded that Minicars would be better suited for medium-than for short-haul trips, and for dispersed ones rather than the trips along high density corridors. Minicars could have a beneficial role in the CBD as long as they would substitute for private automobiles. They would by no means be the dominant mode, but basically complementary to, rather than competitive with public transportation.

## VII. CONCLUSIONS AND RECOMMENDATIONS

### A. Urban Transportation Systems

In order to visualize the Minicar Transit Systems as a potential element of urban transportation, it is necessary to make some observations about urban transportation in general.

The present composition of urban transportation systems is far too limited for the complexity of urban transportation requirements and variety of conditions among different cities. In all U.S. cities, including all types, locations and sizes, a total of only five modes of transportation (rapid transit, bus, private automobile, taxi and walking) have significant roles. Of these five modes, only one, the private automobile, has been adequately financed and intensively developed in recent decades, although it has not been adapted to urban conditions.

There is a strong tendency among urban transportation agencies to believe that systems which are appropriate only for certain types of service are not justified for introduction into urban areas. It is obvious that a greater diversity and sophistication in transportation system selection than presently exists is needed if the complex requirements for service and its impacts on cities are to be satisfied.

However, this does not by any means imply that the introduction of new systems or types of services in urban transportation is a simple task. The Minicar study is a good example of the complexity of such a task. Since the introduction of new systems without coordination with existing ones may cause more harm than good, it is necessary to analyze the potential impact of each new system and examine the required coordination before its implementation. This approach was applied in the Minicar Study. Although the Study was not completed and finally integrated as initially planned, it reached a number of conclusions about the potential role and limitations of an MTS in urban transportation. This chapter summarizes these conclusions and gives some recommendations for further work on this and related problems areas.

### B. Rationale for the MTS Concept

The Minicar Transit System as conceived in the Study can be analyzed as one system in the range of individual urban transportation systems. The existing system of manually operated private automobiles designed according to the criteria for long distance travel is the least efficient system for travel in high density areas. At the other extreme, one can visualize a system of individual "capsules" automatically operated on special guideways which users would get in and get out of according to their travel desires. There

are several basic differences between these two systems. They are: ownership and operation (private vs. fleet), vehicle (standard vs. specially designed), ways (existing streets vs. special guideways) and operation (manual vs. automated). Each of the features of the latter system improves the system's performance in high density areas. For this reason there have been a great number of proposed systems in recent years which would utilize one or more of these characteristics. The systems which would have only one of the new features present small advantage over the existing private automobile system, but would be easier to implement (with respect to planning, design, financing and political and environmental aspects). A system incorporating all these features would offer the greatest benefits, but would encounter tremendous implementation difficulties.

MTS, initiated with the basic purpose of reducing traffic congestion, land requirements for transportation and air pollution in cities, incorporates two of these characteristics: fleet operation and special vehicle design. It has been shown that each of them offers a number of advantages as well as some disadvantages. The frequent comment that this System should be first planned with existing automobiles (e.g. Volkswagens,) cannot be considered invalid since such a system would incorporate one new feature (fleet operation) with the benefits it offers. However the benefits from such a system would be smaller than those from an MTS and the value of an experiment with such a system would be much more limited. For example, if the system would fail either due to low demand or due to economic reasons, one could not categorically conclude that the system is undesirable, since the same system with specially designed vehicles conceivably could have succeeded: the special vehicle design could attract more users and offer greater economies of operation and maintenance.

It can be argued, on the other hand, that the MTS should be tested only with special guideways rather than in the existing streets, since this would bring additional efficiencies in terms of capacity speed, safety, reliability, etc. Compared with the proposed MTS, such a system would, of course, provide higher level of service, reduced street congestion and even lower storage space requirements, but it would require considerably higher investment and present much greater implementation difficulty and uncertainty.

### C. Technological Feasibility of MTS

This study has found that the MTS is technologically feasible. A number of refinements of components developed to date on the vehicle, in the terminals and the information system should be studied further, but none of them is critical for technological feasibility of the System.

The most important result of this Study with respect to the System's technology is development of the prototype vehicle which incorporates a

number of new solutions and conceptually satisfies all the basic requirements of this specialized service. It has a length approximately half that of conventional vehicles, a very low wheel-base/tread ratio and a hybrid power train with a low level of exhaust emissions. With some additional development work, it is very probable that the vehicle will fully satisfy all requirements and be much more efficient in urban conditions than conventional automobiles.

#### D. MTS Functional Feasibility and Applications

From the functional point of view, to offer an acceptable level of service, MTS must provide one of the following types of operations:

1. An area-wide service based on terminals distributed throughout the area with densities determined by travel demand;
2. A service based on a network of terminals located at selected points between which there is an appreciable travel demand and an inadequate (or inferior to MTS) service by other modes; or
3. Special fleet service with a limited number of terminals.

Each of these three types of operations creates a potential for different system applications, which will be summarized here.

An area-wide service with a high density terminal network is economically best justified in central urban areas which have high trip generation rates. The study indicated that Minicars would be most effective for serving trips longer than 1 to 2 miles which do not follow transportation routes. For trips shorter than one mile and longer than 1500 feet public transportation (if organized adequately) is the superior mode in central cities; below 1500 feet walking is optimal for most trips. Thus Minicars would not serve very short, high density trips within a CBD, but rather medium-haul trips with dispersed routing not paralleling public transportation, particularly rapid transit routes.

Trip-rate service, with rates graduated according to distance and duration of use, would in most cases be economically feasible only if combined with some complementary Minicar use which would reduce the fixed charges per trip. Such a use could be for commuting to and from the city, which takes place at times different from those for most trips within the central area. Commuting trips would be charged at a fixed rate per month (flat-rate) regardless of the mileage. Thus the monthly fee would cover the commuting and any additional trips during the evening up to the mileage limit imposed by the fuel supply (users would not have access to the fuel tank). The service would also include parking at MTS terminals.

It has been shown in Chapter V that an MTS would bring considerable benefits to the users and the city, particularly in high density areas, if it diverts trips from private automobiles rather than from public transport. This type of MTS utilization would therefore be most applicable to those cities which have a large central area with moderately high density of primarily office and business activities, such as Washington, D.C. Another MTS application could be in some areas of New York City. In Manhattan, for example, rapid transit service is efficient enough that surface systems do not represent a serious competition to it. Minicars would therefore not divert many riders from it, and would not cause increased street congestion. Minicars would, however, serve that segment of trips which for various reasons requires individual travel; and would do so more effectively and economically than private automobiles. Consequently, there would probably exist a sizable market and an appropriate role for an MTS, particularly for diagonal and other "irregular" trips. Minicars would not, naturally, play any significant role within small, extremely high density areas, such as Midtown and Downtown Manhattan nor for long trips paralleling rapid transit lines. Some of the western cities which presently have inadequate public transportation and an increasing density and parking problem in central areas (Los Angeles in recent years) may also offer potential for MTS application.

Present utilization of taxi service in a city may be used as an indication for MTS potential in it. The two systems provide similar service so that MTS would have a good chance in the cities with extensive taxi system. The cases of Washington, D.C. and New York City, discussed above, are good examples.

The second type of MTS service, with a limited number of selected terminals, may be appropriate for suburban centers and, particularly, for airport access from a number of points throughout a metropolitan area. Since Minicars would be ideally suited for all those trips at the end of which the user would like to dispose of the vehicle for a longer period of time, they would be highly appropriate for access to airports and other transportation terminals. They would increase user convenience, decrease parking requirements and reduce traffic flows since the number of drop-off trips, creating two trips for one passenger, would be reduced.

There are several other types of potential Minicar uses which require study and/or experimentation for each particular case. In all these cases it is clear that there would be considerable benefits from the application of Minicars; the problem in most of them, however, is the uncertainty about the economic feasibility of the System due to the limited utilization of vehicles. Several examples of such additional uses are described here.

Use of Minicars as feeders for rapid transit systems in suburban areas is in some respects more convenient than their use in central areas. The distances traveled by suburbanites to rapid transit stations are usually greater than access distances within the central areas; traffic congestion on streets is lower; and, availability of land for terminals at the stations is greater. The main problem is securing sufficient utilization of vehicles which would permit acceptable rates for their use. In cases where rapid transit stations are located beyond walking distance from other traffic generators, the Minicars would be utilized only for approximately two trips per day, thus requiring excessive rates to achieve the Systems's economic feasibility. In cases in which the station is in the immediate vicinity of high density apartments, the Minicars could be used during the day by the apartment dwellers for their shopping and other trips, thus increasing vehicle utilization and permitting lower per trip charges.

Travel from inner urban to the suburban locations ("reverse commuting"), which has become a particularly serious problem for low-income residents, would be another desirable use for Minicars. Suburban workers who live in the city could either drive Minicars from their homes or take a commuter train to a suburban station, where they would pick up Minicars and drive to their work locations. In some cases the timing would be such that suburban commuters and reverse commuters could use the same vehicle. The remaining problem is again to find a supplementary use for the vehicle once the worker has arrived at the suburban plant. There are two possibilities for covering the cost of this use of Minicars: the plants may use them during the day for travel by business officials or messengers and other supporting personnel; other possibility for maintaining the economics of the MTS could be an allowance by the plant to Minicar commuters, either reflecting the reduced terminal requirements (as compared with parking facilities for private automobiles), or for social reasons in cases of workers from areas of high unemployment.

The third type of Minicar application would be special uses as leasing of Minicars by various companies and government agencies which presently use fleets of vehicles. They could rent Minicars at considerable savings in comparison with rented automobiles. Such users include the Post Office Department, insurance and service companies, various traveling salesmen and other similar businesses.

#### E. Economic Feasibility of MTS

The economic feasibility of the MTS depends, of course, largely on the level of demand for the system. Since the Minicars would be available only at the terminals, the MTS requires, similar to line-haul public transportation, a certain concentration of travel demand. In area-wide applications the System

operates ideally in zones in which there is a rather high demand density for travel in dispersed, irregular directions. The System's economic picture deteriorates rather fast with decrease of trip density. Since fewer terminals would be economically justified in lower density areas, the attraction of the System would be lower and it would therefore capture a lower percentage of the demand than in higher density areas.

The estimation of the economic feasibility of an MTS for Philadelphia performed in this Study found that the System, as conceived, would be feasible and even produce profits. However, since that estimation was based on demand projections, it is only as reliable as those projections are. As discussed in Chapters III and IV there is presently no method to make demand estimates for a future transportation system with a high degree of reliability. The differences in projections by the different methodologies performed in this study are appreciable, illustrating this problem. The relative uncertainty of demand projections represents the basic unknown factor about the MTS.

It does not appear that this problem of projected demand, critical for the whole system, can be satisfactorily resolved by further theoretical studies alone. Behavior of people and their acceptance of a new transportation concept can be reliably determined only by actual testing.

The importance of improved demand estimates through actual experiments is emphasized by the finding of the economic study that system feasibility is highly sensitive to demand and revenue estimates. Vehicles cost is the second most critical item for feasibility, but its estimate is more reliable than that for demand. All other items are considerably less critical for MTS economics.

Although detailed studies of demand and economic feasibility of MTS application for travel between a selected set of points, such as airport access, has not been performed, indications are that such uses would have a reasonably high probability of success. Since such a system, with a limited number of terminals, would be easy to organize, it would be appropriate for an MTS experiment. Following the introduction and initial testing of that system service could be broadened step by step to an increased number of points, exploring its optimal domain.

#### F. Desirability of MTS

It was shown in Chapter V that utilization of Minicars instead of private automobiles results in a number of user and social benefits; the latter ones are particularly important for alleviating the serious problems in urban areas. Substitution of travel on public transport with Minicar travel, on the other hand, has more negative than positive effects. Consequently, the desirability of an MTS will greatly depend on the pattern of diversion of trips to the MTS:



diversion of trips from private automobiles should heavily outweigh (by a ratio as high as 5:1 or 6:1) diversion from transit to make the system socially desirable.

An important conclusion of this study is that the social desirability of MTS does not necessarily coincide with its maximum use or maximum revenue. In some situations it may be necessary to apply rates different (higher or lower) from those which would maximize the operator's profit. But with public regulation or ownership of the MTS it is entirely feasible to provide pricing and other operating policies which will ensure that the system is socially desirable.

Specifically, the policies to achieve a desirable employment of Minicars could be realized through the following measures:

1. The rate level and structure could be carefully determined so as to avoid price competition between the MTS and transit.
2. In some cases differential prices by trip orientation and time of day could be set up so that, for example, peak hour trips paralleling transit would be discouraged.
3. Distribution of terminals could be made such that utilization of Minicars is stimulated or discouraged according to the desirable role of the System in specific areas.

This study has also found that if an MTS were introduced into a city without any changes in the existing conditions and policies, some of its benefits would be either reduced or completely offset by such problems as lack of enforcement of traffic and parking regulations, parking rate structures set-up in the interest of individual operators (e.g. parking lot owners) rather than the public, etc. Thus, it would be highly desirable, if not imperative, to change policies toward other modes also. Some such measures would be:

1. Introduction of progressive rates for parking in business and shopping areas (low charges for short parking, high per unit time rates for long-term parking) to facilitate the business travel which must utilize automobile and discourage commuting by private automobiles.
2. Drastic improvement of transit service for short-haul travel within high-density areas (either by improved existing service, information and special fares; or by a new "ubiquitous network" of minibuses, as suggested in Chapter VI). There are presently extensive studies of a number of new systems for this application. Most of these systems are new and untested, and would present considerable implementation difficulties. While these systems are very desirable for long-range improvements of transportation in urban centers,

actions suggested here would bring immediate results and would be, in most cases, much more cost-effective in the short and medium run. This improved service would by itself discourage people from transferring from transit to either private automobiles or Minicars.

3. Introduction of special combined (joint) fares for transit and Minicars, thus stimulating usage of Minicars as collector-distributors for transit.\*

In summary, MTS requires careful planning and coordination with other transportation modes in each individual case if it is to achieve the goals of its introduction; improved transportation and reduced negative side effects. The planning and coordination of current modes is needed and overdue in many cities even if an MTS were not introduced. MTS may therefore act as a convenient cause for such improvements, which would represent an additional significant indirect benefit from its introduction.

#### G. Significance of MTS for other Small Vehicle Systems

The analysis of the relationship of MTS and other Systems in Section VII-B indicates clearly that a number of findings and conclusions about MTS have a direct bearing on a number of other individual transportation Systems. Since most semi-and fully automated systems would be based on the concepts of special vehicle design and renting for individual trips or short terms, they would have similar planning and operating problems as the MTS. Need for experimentation to obtain a reliable estimate of demand is also shared among all these systems.

The significant point is that it would be much easier and require a lower cost to organize an experiment with an MTS than with systems requiring private or special guided rights-of-way. The MTS therefore represents the first logical step in examining the feasibility and desirability of such systems. Experimenting or planning of such systems as Urbmobile, Alden Starrcar, Teletrans and others should be preceded by, and based on, the experience from the tests with an MTS.

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\* In Hamburg, Germany, following a complete unification of fares for all transit services in the city, a trial operation of combined fares between transit and taxis has been introduced. Results of this test should be relevant for potential similar applications of Minicars.

## H. Recommendations

Based on the results of research performed within the Minicar Study, summarized in this Chapter, the following recommendations are made by the research team:

1. An experiment with the Minicar Transit System should be organized in a large urban area. The System should be planned for a carefully selected purpose, such as to provide transportation between a number of points within the area and the airport. Selection of the best city for such a test has not been completed and requires additional study.

2. The experiment should be undertaken with the Minicars developed in this Study. An experiment with conventional vehicles is possible, but would yield results of a much more limited conclusiveness.

3. Careful surveys of users and system operations should be planned for the experiment in order to obtain actual data on the problems which cannot be resolved by theoretical studies only. These problems include, above all, demand estimates; then, other aspects of public attitude toward such a system, including vandalism; impact of Minicars on travel patterns and traffic behavior; and, various aspects of terminal operations and vehicle redistribution.

4. Evaluation of the MTS experiment results should be done on a comprehensive basis, i.e. including all social and economic side effects; the profitability of the System is an important but not exclusive factor in determining the System's desirability.

5. Due to the need for a comprehensive approach, the Federal Department of Transportation is the most appropriate body to undertake an MTS experiment and supervise its planning and operation.

6. Further studies should be pursued in conjunction with an experiment in the following areas:

- a. Development of reliable methods for projection of demand of new transportation systems;
- b. Further analysis of legal and organizational aspects of an MTS and related systems;
- c. Optimization of the Minicar prototype based on the results of this Study;

- d. Parking area requirements for Minicars, based on different patterns of their use;
- e. Simulation of traffic flow on multi-lane streets;
- f. Redistribution of vehicles.

All of these studies should be organized so that they have validity for MTS as well as related systems with individual rented vehicles.

7. Transportation in central business districts of most large cities should be significantly improved in a short period of time by providing "ubiquitous mobility" throughout that area. This can be achieved by:

- a. Improved utilization of the existing public transportation through integrated information for all services and special fares for rides within that area.
- b. Introduction of a network of Minibuses which offer frequent, low-cost service.
- c. Encouragement of walking through improved conditions for pedestrian movements. Immediate improvements can be achieved through better regulatory measures; long range through improved "pedestrian-oriented" planning and design for these areas.

All these possible actions should be analyzed for each individual city. Provision of such ubiquitous service by either of these systems should be coordinated with other transportation policies, since such service would permit an energetic discouragement of parking in the area and consequently, reduction of traffic congestion. The impact on central cities of such improvements would be very significant and social benefits would be high. Reduction of private automobile traffic through substitution by rented vehicles (MTS) or public transportation, and its improved regulation, is the only way to improve mobility in central Cities.\*

### I. Summary

In final conclusion it can be stated that the MTS has potential for a number of different types of applications in urban areas. The MTS was not conceived to be, nor would it be a major, dominant urban transportation system; but if carefully planned, it would yield a number of benefits.

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\*For a more detailed analysis of this problem, see: Vuchic, V.R.: "Concept of 'Ubiquitous Mobility' for Central Urban Areas" to be presented at the 38th National ORSA Meeting in Detroit, October 1970.

In most of its uses diversion from private automobiles to Minicars would be socially desirable; diversion from public transport would be undesirable and it should be prevented. With careful planning this kind of control is feasible.

The basic uncertainty about the MTS feasibility in individual applications is the level of demand for it. Public acceptability of a transportation system-particularly one based on a new concept-is extremely difficult to predict. More reliable demand projections than those performed in this study would require an actual experiment of the system. Further studies of MTS components and experimental operation would yield valuable data not only for a reliable definition of the MTS role in urban areas, but also for evaluation of the potential for a number of other new and more sophisticated systems based on similar concepts.

## Technical Supplement S-I

### THE VEHICLE

#### A. Introduction

A specially designed vehicle - Minicar - is a part of the Minicar Transit System concept. The reasons for special design of a vehicle rather than utilization of one of the existing automobiles have been presented in several preceding reports of the Minicar Project. A discussion about the significance of a specialized vehicle for the MTS concept is presented in Sections II-B and VII-B. Stated very briefly, a specialized vehicle would increase the initial cost of the System, but would result in significant savings and benefits during the System's operation, which would be accrued by the operator, the users and the City. While experimentation with the MTS concept with existing vehicles might be possible, its results would probably be inconclusive, particularly if they happen to be predominantly negative. This inconclusiveness would, naturally, defeat the purpose of the experiment.

The requirements on which vehicle specifications are based are drastically different for Minicar as compared with those for conventional automobiles. The main differences are:

- Minicar trips would be generally short, mostly at low speeds in high density traffic and without major requirements for luggage and other facilities.

- Rental operation of Minicars would reduce requirements for personalized design of vehicles and makes necessary provision for the vehicle to be driven by many drivers, instead of one or two as is usual with privately owned automobiles.

- Fleet ownership would permit high standardization of maintenance procedures.

- Since the Minicars would be used in urban areas, it is most important to minimize their parking requirements, exhaust pollution and noise, while maintaining their agility for mixed traffic.

Based on these specific requirements for the Minicar, the following basic specifications for the prototype vehicle were developed in Phase I of this Study.

- (i) Length - 9'0"; width - 6'4"; height - 4'8"; capacity - 3 passengers;
- (ii) Dynamic performance comparable to that of existing compacts;

(iii) Low exhaust emissions plus possibility of limited range operation with no emissions;

(iv) Passenger safety at least equal to that of currently conventional automobiles;

(v) High operating reliability;

(vi) Adequate passenger comfort, including air conditioning, and attractive appearance;

(vii) Durable, rugged and simple to maintain.

Some vehicle features satisfying these specifications, such as a hybrid gasoline - electric power train and automated diagnostic and maintenance operations, were conceived in Phase I of the Study. This Chapter summarizes the design of components and prototype construction and testing which took place during Phase II.

## B. Body<sup>\*</sup>

### 1. Physical Dimensions

In order to reduce space requirements in streets and parking facilities, a basic dimensioning criterion was to minimize the length of the Minicar, subject to the constraints of vehicle performance, passenger comfort and safety. It was found that an overall length of nine feet, or approximately one half of the average conventional American car would satisfy these requirements. With one foot of front overhang, this length allows the vehicle to be parked perpendicular to the curb within the standard eight to ten foot wide parking lane, thus occupying only approximately 30 per cent of the curb length required for a standard parallel curb parking space.

Since the Minicars will not utilize special lanes or guideways (at least in the first stage of development), no savings in lane widths can be achieved by reducing the vehicle width. Thus, the width has been determined so that the vehicle can comfortably accommodate three passengers, a capacity which is considered desirable for the purpose of the System. Presently the width of the Minicar is planned to be 78 inches with a maximum outside height of 59 inches. The curb weight of the vehicle with full fuel tank and three passengers would be designed for a value in the range at 2750 to 3500 pounds.

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<sup>\*</sup> See references [T1a, d and e].

## 2. Exterior Design

An important requirement in development of the Minicar is that its exterior styling create a pleasing impression in the minds of potential customers for purposes of enhancing MTS usage. An overall exterior view of the prototype is shown in Figure 1, p.7. Evidence gathered to date in "Product Clinic" and other showings of the Minicar styling buck suggests that the present exterior appearance is reasonably close to that ultimately desired.

## 3. Interior Design

The Minicar interior would be designed for optimum safety, comfort, utilization and maintenance, and specifically for use as an urban vehicle (short trips). The interior of the Prototype is shown in Figure SI-1.

The Minicar is designed with a 15-inch vertical distance from the seated passenger's H-point\* to his heel (as compared to Cadillac's corresponding distance of 9.2 inches), thus increasing seating comfort by opening the knee bend angles of the occupants. Furthermore, this extra seat height considerably eases ingress and egress from the Minicar, especially when it is parked at a curb.

All hand and foot controls are adjustable to accommodate, by means of a movable toeboard, a wide range of driver sizes (estimated at approximately 2.5 percentile adult female to 97.5 percentile adult male). An additional feature of this system is that the seat need not be moved forward when the driver is small, a circumstance which in conventional cars restricts the leg room available to the other front seat passengers. Except for the movable toeboard, all controls are purchased OEM parts meeting government and SAE standards.

The Minicar seat being fixed in position is located toward the rear of the passenger compartment to improve comfort and crash protection for the passengers. The seat is contoured to fit a wide range of passenger sizes while offering good support to the lumbar area of the back. It consists of rubber diaphragm suspension and foam padding. This type of construction is efficient in reducing high frequency inputs from road shocks. Final diaphragm and foam thickness will be tuned to minimize dynamic road shock inputs.

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\* The passenger's "H-point" is the projection on his hip of the "hinge axis" running through the joints of the femur with the pelvis.



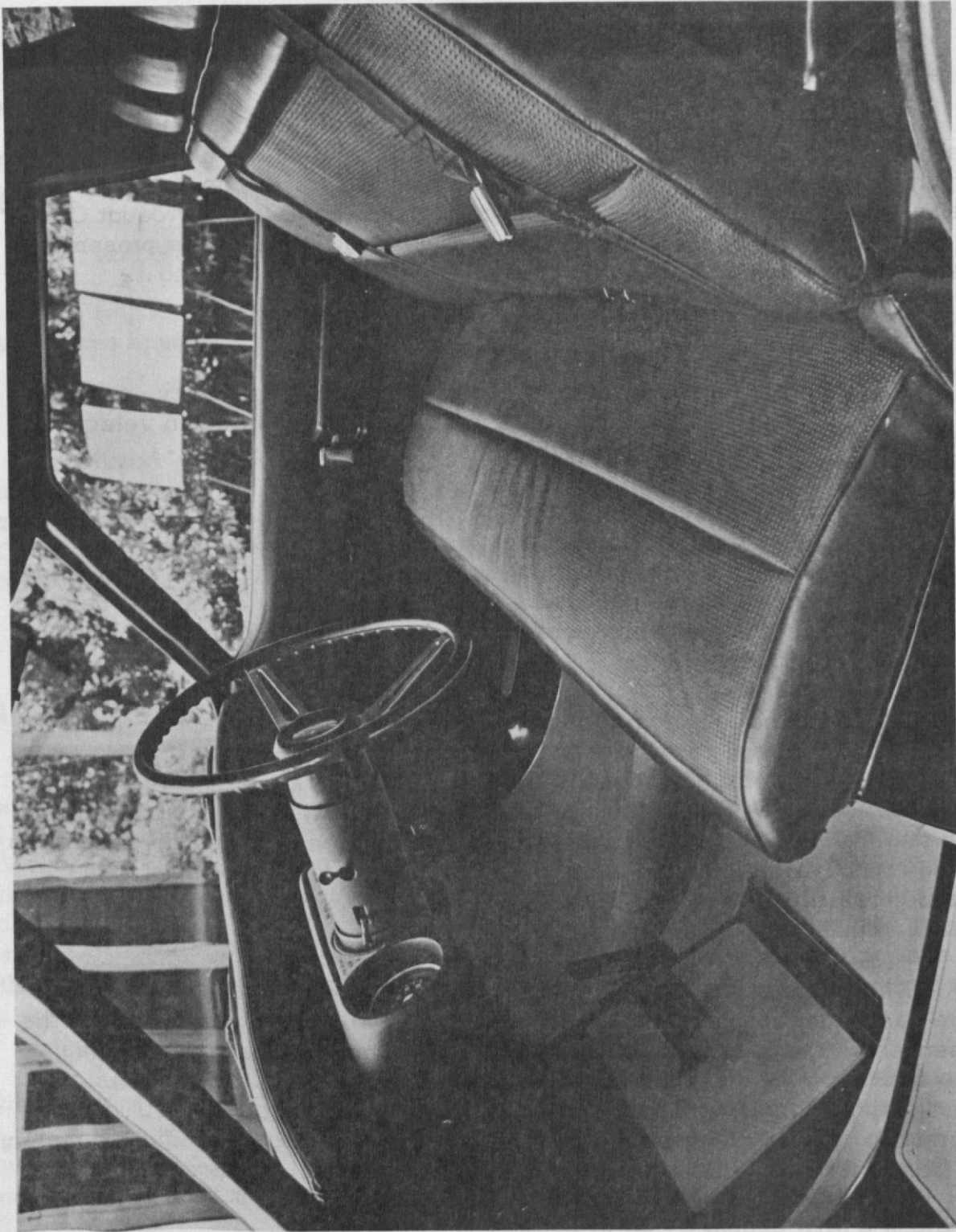


FIGURE SI-1. MINICAR INTERIOR

A unique lap-and-shoulder harness as more fully described under "safety" has been designed both for easy use and effective restraint of the Minicar's occupants in event of a collision. A single latch fastens and releases the entire harness. If a seat is occupied by a passenger, a switch in its bottom cushion detects his weight and another switch in the upper reel of the harness then prevents driving the car unless that passenger's restraint system is properly secured. The entire harness, when disconnected, stores neatly against the seat back, thus facilitating egress for the center passenger. Both shoulder and lap belt elements of the restraint exceed the SAE load specifications.

No special provisions for combating vandal-type attacks have been included beyond designing all interior items, surfaces and materials for ruggedness and reliability under the anticipated handling conditions of the general public. Analysis shows that vandals working with knives, hammers and so forth cannot practically be combated through increasing ruggedness of design, so it was decided to attempt to meet the wanton damage problem by (i) providing a "quietly luxurious" compartment which implicitly conveys to all customers that they are being treated as befits responsible users of a quality product, and (ii) making all interior parts of low-cost, easily-replaceable, unitary construction.

The Minicar interior has been specifically designed for automated cleaning through the proper placement of drain-type openings and the avoidance of crevices or corners where dirt can lodge.

The luggage compartment is of prismoidal shape approximately 70 inches wide, 12 inches maximum length and 16 inches high. It is capable of taking up to three suitcases of the largest carry-on air travel size.

#### 4. Chassis

Three basic concepts were considered in the chassis design:

- (i) Tubular or (channel) perimeter chassis;
- (ii) All monocoque body-chassis;
- (iii) Platform and subframe (center tube frame).

For reasons of safety, and to keep intrusion into the driver compartment to a minimum, the tubular construction, illustrated in Figure SI-2 was chosen for the prototype chassis. The design evolved into a very rigid frame, circumscribing the passenger-driver area on all sides, and elevated at the fire wall and at the roll bar. A 4 x 4 x 11 gauge tube of 1018 mild steel was chosen for this rigid frame. Attached to it at the front, via a set of rotating mounts above

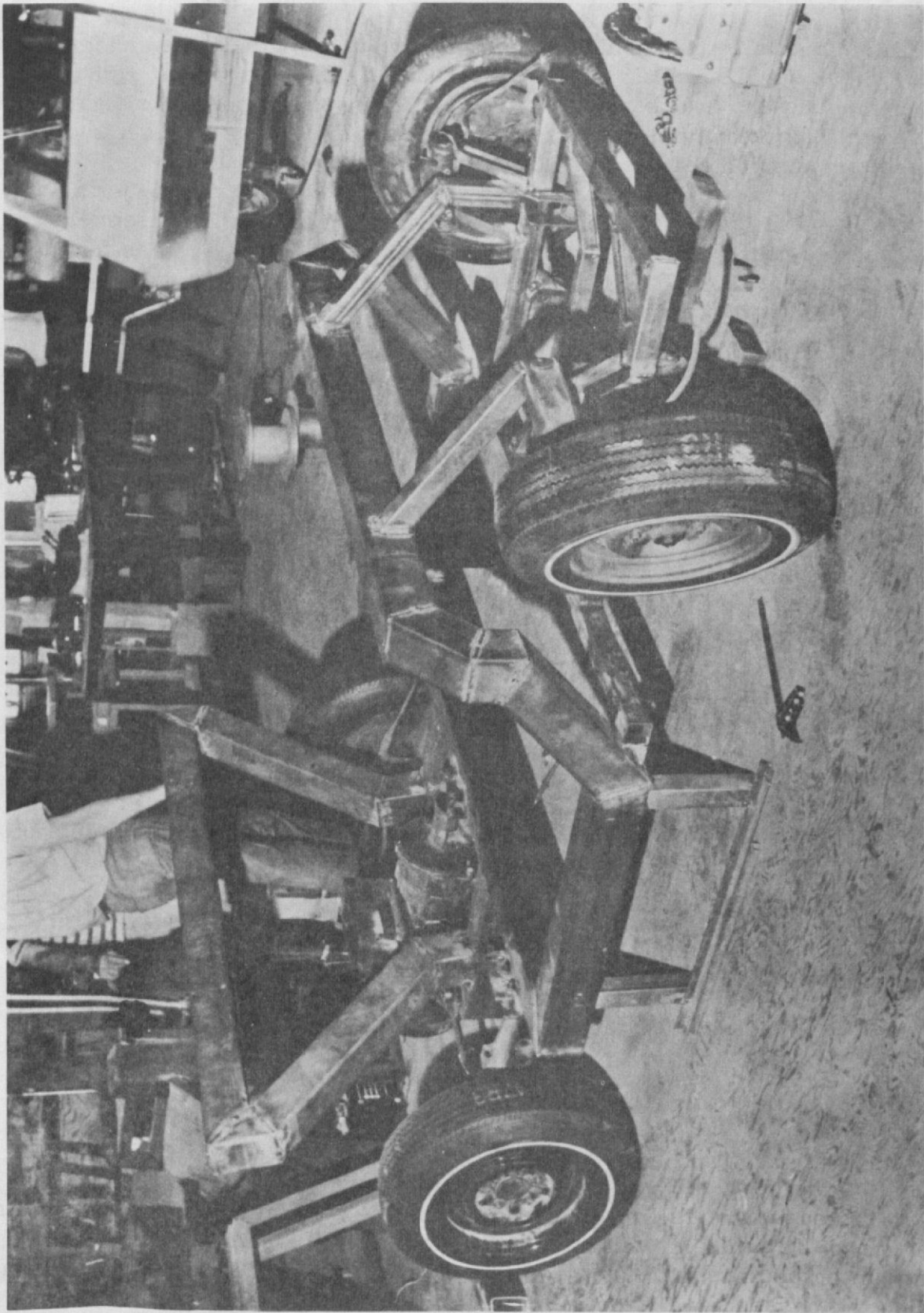


FIGURE SI-2. CHASSIS CONFIGURATION

the engine and a set of shear bolts below the center line of the siderails, is a subframe which unites the engine and front suspension components, steering gear, and three of the five batteries. The entire structure is so designed that under a heavy frontal impact the lower shear bolts break off, and allow the whole subchassis to rotate under the main rigid frame, carrying with it the engine and components.

## 5. Body

a. Material. A review of existing body construction techniques and tooling technology led to the conclusion that a Fiberglass Reinforced Plastic (FRP) body best meets the requirements of economy, feasibility strength, durability, finish and reproduction. FRP has had extensive usage in the automobile industry and requires no technological advances. It is very suitable for limited production vehicles. Tooling of fiberglass molds is very inexpensive when compared with tooling for any other suitable body material.

Other materials investigated included sheet metal (steel and aluminum) and thermo-formed plastics of the Acrylonitrile-Butadiene-Styrene type. Sheet metal, being the oldest and most widely used of all body materials, requires no new fabrication technology; however, it is extremely expensive and it is unrealistic to consider for limited production runs. Handformed sheet metal was also considered. While this requires no large tooling investment, it does require highly skilled and therefore costly labor.

Communication with the manufacturers of several of the newly developed thermo-formed plastics showed that these materials are available in a variety of configurations. The ones primarily being used include foam filled sandwich material and sheet stock. It was found that base material cost approaches that of fiberglass (although neither are as low as steel). The tooling for the ABS materials consists of steel molds to which heat and vacuum systems must be applied. Tooling costs per unit are therefore very high when compared with fiberglass. ABS is difficult to mold in small details such as door flanges or mating surfaces. Therefore other assembly steps are required so that these details are included on finished parts.

In terms of finish, molded fiberglass parts are an advantage over steel in that the molded material can be color impregnated and retain any surface finish desired, while steel components require surface filling, priming and painting. The thermo-formed ABS plastics can be mold finished in much the same way as the fiberglass.

The prototype Minicars are designed with large foam-filled sections incorporated into the body shell providing crushable energy absorbing characteristics. The same design using steel or ABS bodies can be accomplished but with higher tooling costs.

b. Topological Body Design. The basic topological body is being designed as a single part which includes the seats, floor pan, rear package tray, rear wheel wells and front fender surfaces. The part is designed to fit over the present chassis configuration and clear its members by 1/2" from finished FRP surface to steel. The body is mounted to the chassis on rubber pads and mechanically fastened.

The upper body consists of two basic components: an exterior shell and an interior shell. The interior shell has a finished inside surface, since it is molded on a male internal mold. The part integrally carries the door flanges, the interior "A" and "B" pillars, the head liner, quarter panels, and rear interior panels. This part eliminates approximately 80 parts now used to assemble the upper body in a conventional car. The interior and exterior shells are bonded together in a fixture in which the roll bar has been located so that it is formed in place between the two elements.

The roll structure is used for hard-point attachment of the driver and passenger shoulder restraints and lap belts. Another feature of this structure is that it contains the fuel tank in a solid steel structure perimeter, thereby reducing the chances for any spillage of fuel from a punctured or collapsed tank. The roll structure also carries the rear coil spring mounts and provides for the attachment of side control arms for the rear suspension.

The roof section has been positioned so that a 97 percentile male has 2" of head clearance to the top liner. This section is virtually flat so that the same head room exists for all three passengers.

In general, the topological body construction, while not only providing assembly and manufacturing advantages, also stiffens the sheet metal elements of chassis and provides a virtually leak-proof floor for the passenger compartment to exclude water, carbon monoxide and road noise.

c. Doors. Conventional door construction techniques have been examined and found incompatible with the Minicar in terms of passenger safety from side impacts. The door construction chosen for the prototype is one of composite materials and is compatible with the adopted body building techniques.



A parallel hinged door is provided for maximum density of storage in parking areas. The opening dimension is 28". The door consists of an exterior skin and an interior shell. The interior shell completely frames the window glass in order to avoid the fabrications of special moldings for the windows. The door sections will be assembled by the technique of foamed-in-place urethane. The door liner in this design is an extremely important part, since it carries the door flanges, the window molding flanges, and all the receptacles for door mounting hardware. The parallel hinge and latch mechanisms are accommodated in a steel box section which lies inboard of the door liner. An AMC flush mounted handle is used because of its adaptability to any mechanism which is generated to actuate the door latching and locking. The door molding will be configured to accept either safety glass or plexiglass mounted in MOPAR rubber molding. Sliding window assemblies can also be accommodated by the rubber molding to fiberglass edge technique.

### C. Propulsion System\*

#### 1. Introduction

Development of the Minicar propulsion system was based upon the following basic requirements:

- (i) Minimum exhaust emission;
- (ii) Adequate dynamic characteristics for operation in mixed traffic on existing local and high speed facilities, compatible with present day all-purpose highway passenger vehicles;
- (iii) Long life with minimum maintenance (approx. 150,000 miles total, with 75,000 miles between major overhauls);
- (iv) Maximum reliability;
- (v) Low initial cost and running cost;
- (vi) Small size and low weight (max. 400 lbs);
- (vii) Minimum noise.

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\* See references [T-4b,c,f through j, l and m].

Many types of propulsion systems were investigated at varying levels of detail. The optimal system for the current Minicar concept was found to be a hybrid power plant consisting of an internal combustion engine (ICE) and an electric motor. The two units and the battery are interconnected and controlled so that the ICE acts as the main propulsion unit during normal operation. In periods of peak tractive effort, such as initial acceleration and hill climbing, the electric motor contributes to the power output. During idle, cruise and deceleration periods the ICE rotates the electric motor which is acting as a generator, thus recharging the battery, and also providing regenerative braking.

The development of the propulsion system under this phase of the Minicar Transit System Study essentially began with Prototype A, a full scale experimental vehicle utilizing an ICE. This work was followed by experimentation on an ICE and motor/generator system designated the DAF hybrid power train. Next, a system involving an electronic armature controller was investigated. The application of a steam engine to the Minicar was analyzed. A d-c motor/generator for the hybrid system was investigated and designed. Subsequently the first full scale hybrid vehicle, Prototype B, was designed and constructed. The power train units and controls including exhaust emission control were tested and analyzed. Further testing and future design recommendations are summarized here.

## 2. Prototype A

The first experimental vehicle constructed for the Minicar Transit System, Prototype A, was powered by an ICE with automatic transmission. While far from a production prototype, this vehicle was intended to resolve many of the fundamental feasibility questions in power train performance, suspension, ride, handling, and safety areas.

The Prototype A vehicle components and general characteristics are as follows:

Car weight	1850 lbs. empty, 2300 lbs. total test weight
Car frontal area	25 ft. <sup>2</sup>
Motor	Modified Corvair 6-cylinder opposed ICE, air cooled, 9.5/1 compression ratio, 153 in <sup>3</sup> displacement.
Final Drive	Modified Pontiac Tempest, automatic transmission

The testing of performance and handling characteristics of Prototype A consisted of a series of acceleration and deceleration runs, a top speed trial, and various cornering maneuvers. A static test preceded this which determined overall weight, weight distribution, and available power from the engine. The vehicle was installed on a chassis (road) dynamometer. Power readings were taken in "drive" and in "low" range at various speeds (10 mph increments) at wide open throttle. While the vehicle was still on the dynamometer a flywheel with equivalent mass was used to check for acceleration. A fixed road load setting was set into the dynamometer and acceleration runs from 0 - 40 and 40 - 60 mph were made. Performance curves were developed from the test results showing power requirements, maximum power available over the entire speed range, and acceleration capabilities.

### 3. DAF Hybrid Power Train

The objective of this task was to investigate and verify the feasibility of an experimental parallel hybrid engine operating at the 30 hp power level. The system consisted of ICE motor/generator and torque converter. As a breadboard type system, the vehicle could be used to develop and optimize a control system that could solve basic hybrid interface problems (ICE coupling to electric machine). Starting with a manual control, the system objective was a fully automatic operation with good interface of the mechanical and electrical systems. Once the control system was improved, the vehicle could be tested so that data could be obtained to eventually make predictions of a hybrid prototype vehicle's performance.

a. System Objectives. The objectives of this parallel type of hybrid system are reduced emissions from the ICE and a short-range. All electric capability is to be used in areas requiring zero emission characteristics (long tunnels, underground garages, etc.). To accomplish this, a d-c motor/generator is coupled to an ICE via a common center shaft with the center shaft clutch coupled to the drive train of the vehicle as shown in Figure SI-3. Acceleration power is supplied by the d-c motor. Power for the road and accessory loads, including the generator load, is supplied by the ICE. It is a basic characteristic of an ICE that emissions are increased under the load of acceleration. Also, an engine running in a more or less constant power range produces less pollutants than one running over a largely fluctuating power range. When the hybrid vehicle accelerates, the d-c machine acts as a motor and both the ICE and the motor supply power for propulsion. The added power of the d-c motor reduces the total power required from the ICE and thus, the emissions. After the vehicle reaches the desired speed, the control system switches the d-c machine to generator mode and the battery pack is recharged.



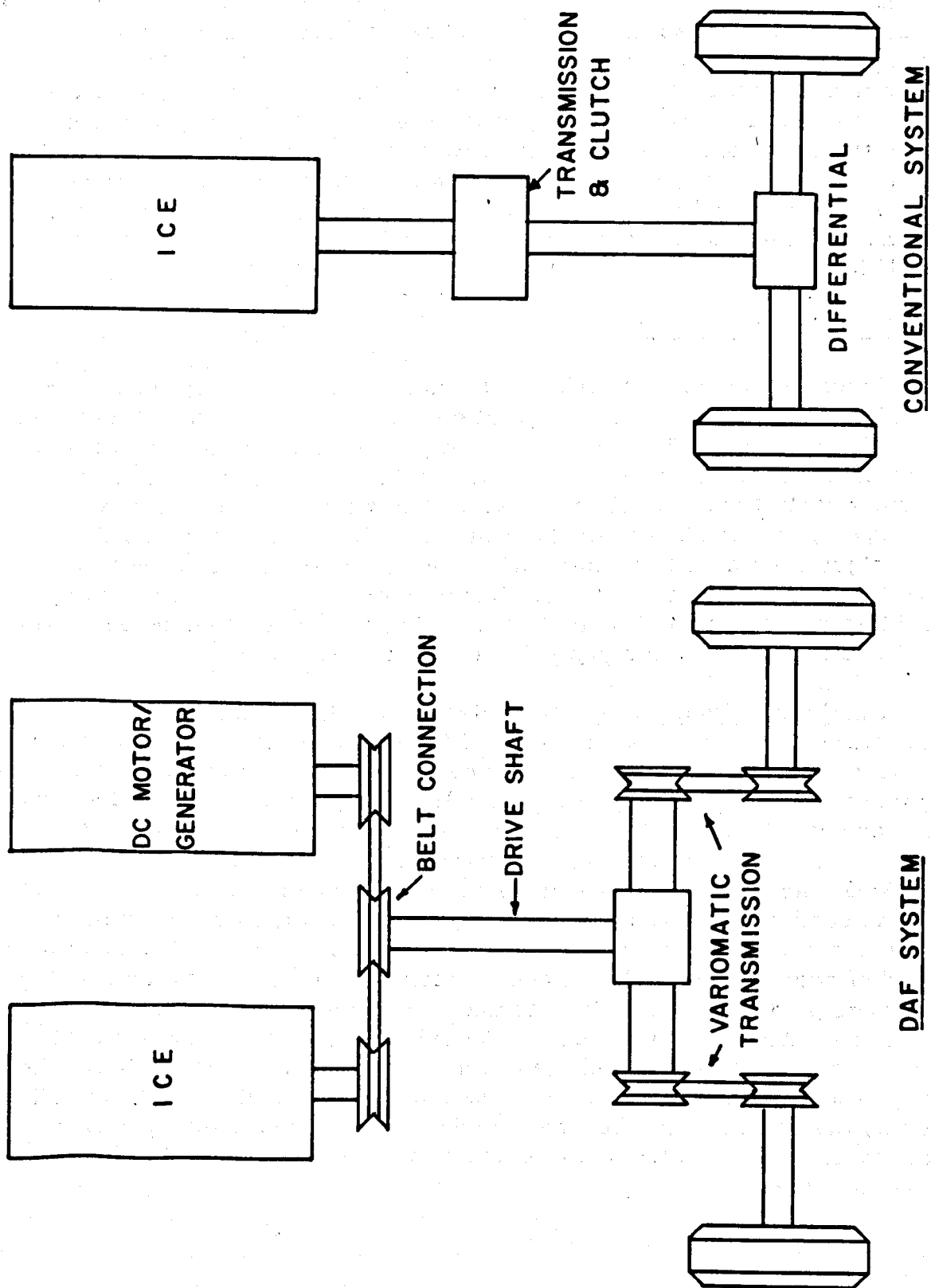


FIGURE SI-3. POWER TRAIN SCHEMATIC

b. Components. Because of space considerations, a small, light-weight, air-cooled, 2-cycle ICE of the 20 hp range was used. The ICE selected was a Curtis Wright RCI-18.5, 20 hp (Wankel) air-cooled, rotating engine.

A shunt type d-c motor/generator of the 10 hp range was selected in order to meet the electrical and acceleration requirements of the hybrid. The specific machine chosen was a 9.5 hp Jack and Heinz Model DA17-4, operating on 27 volts and 330 amps.

The battery requirements were met through the use of four 12 V, 100 amp-hour lead acid automotive batteries installed in the trunk compartment of the vehicle.

A 1960 DAF 600 automobile was selected as the vehicle most suitable for the program objectives. The DAF is a small, Dutch compact that uses a unique device called the "Variomatic" transmission. Power is transmitted through a centrifugal clutch to a variable ratio V-belt transmission. The original ICE control accessories were removed.

c. Testing and Results. Bench tests were conducted to determine the generating characteristics of the Jack and Heinz motor.

Road testing was conducted and it showed that basic hybrid action was possible. However it was found that generated voltage was a poor basis for mode switching. Since the switching point was dependent upon the setting of the manual speed control potentiometer, inconsistent operation resulted.

A modification of the control system was made by the addition of an accelerator coupled switch for road load sensing. Road tests showed better control system operation. Investigations of automatic motor speed controls were started with this control system.

A third control system was then investigated. It utilized two alternate methods of motor speed control, replacing the carbon pile with a voltage sensor, installation of a vacuum switch and replacement of the carbon pile voltage regulator with a modified and improved unit. The best method of sensing road load requirements proved to be with the use of a vacuum sensor coupled to the manifold of the ICE. The alternative system investigated, a solid state field current amplifier using an electric vacuum transducer, proved feasible, but more investigations need to be conducted.

Dynamometer tests were performed with a Clayton chassis dynamometer. Acceleration testing was done on a level road. Velocity acceleration and power curves were developed for both an all-ICE system and the full hybrid system. A level-road-load curve was computed and total road horsepower graphs were plotted, thus deriving power supplied by the electric motor. Tests were then done to obtain data of ICE vacuum at various speeds. The DAF was subsequently put on the chassis dynamometer and load adjusted.

Hydrocarbon emission tests were run for the ICE and hybrid systems using the LA-4 road cycle. It was concluded that before valid test results can be obtained, careful control must be gained of the variables of the experimental conditions. New experimental techniques were subsequently investigated.

A test was done to determine the all-electric capability of the vehicle. The vehicle was capable of 11 mph maximum velocity with a field current of approximately 0 amperes and an armature current of 300 amps. Further tests will be necessary to determine the vehicle's range for all electric operation.

The vehicle was driven 260 miles on public roads and city streets. Among the test results were the following:

Operation of the control system was smooth and reliable. The vehicle can be driven in essentially the same manner as a conventional car although the vehicle involves a scaled down power plant, and thus has reduced performance characteristics. At speeds below 25 mph it was able to keep abreast of traffic flows and function as well as a conventional compact car.

d. Conclusions. The major purpose of the DAF development was its use as a breadboard hybrid. This breadboard allowed trial of new hybrid experiments never done previously. Three major control schemes were tried with numerous modifications in each scheme. One major power train was used but many modifications, such as gearing, coupling, etc. were also tried. Further prototype design groundwork was laid by the experience gained from the DAF system. Many theories that could only be answered by empirical methods were proved or disproved. In short, the DAF laid the necessary ground work for future prototype hybrid designs.

#### 4. Electronic Controller

An investigation was made of the feasibility of combining a Minicar chassis and a Corvair engine in a hybrid system involving an electronic armature controller (EC).

The motor/generator and ICE were connected in parallel by a clutch, without transmission. The motor mode was controlled by the EC, and the generator mode of operation was controlled by a solid state voltage regulator.

Specifications for the motor/generator were developed on the basis of the requirements for the maximum acceleration characteristics desired for the vehicle. However, the desired unit was not obtained. Therefore, an all-electric chassis, employing compound type machines, was utilized.

Specifications were developed for the EC. An armature control unit manufactured by Exide Power System Division, Model No. 36-SS-700 with 36 VDC max. output voltage, and 800 amp. max. output current was selected. Some modifications were made for adaption to the system.

In the experimentation it was extremely difficult to achieve perfect compatibility between the starter, generator and electronic controllers. Attempts at obtaining a motor applicable both to the controller and the hybrid vehicle were unsuccessful.

In conclusion, the major advantage of the EC over a field control system as used in the DAF or Prototype B is the increase in speed range of the electric motor. This increase allows the transmission to be replaced by the electric motor and the EC. Power efficiencies are greater with the EC than for a torque converter or automatic transmission system. Substantial saving in weight is realized by the EC over the automatic transmission. Relative complexity of the two systems is nearly equal. Reliability is also comparable, although replacement of EC components may be more expensive. The principal disadvantage of the EC system versus the automatic transmission is the significantly higher cost.

In view of these considerations the Prototype B, vehicle was constructed utilizing an automatic transmission instead of an EC. Further investigation of forms of EC other than armature may be warranted. Alternatives other than an automatic transmission deserve future consideration.

## 5. Steam Engine

The application of a steam engine as a power source for the Minicar was investigated. A study of the developments, status and characteristics of the predominant types of steam engines under design in the country was made. Their adaptability to the MTS vehicle was analyzed. The principal aspects used in comparison with other forms of propulsion plants were emission, reliability, maintenance, economy, noise and availability.

In summary, the investigation concluded that emission characteristics provided a distinct advantage over the ICE. With respect to noise level, maintenance characteristics and economy, the steam engine offers limited advantages over the ICE. Reliability, complexity and safety are approximately equal in the two basic systems. Disadvantages of the steam engine lie in its larger size, longer start up time and current lack of availability of a reasonably well optimized engine.

In view of the numerous potential advantages of the steam system further development of its design should ultimately result in a power plant worthy of more detailed investigation for adaptability to the Minicar.

## 6. Minicar d-c Motor Design

A summary of the principal design considerations and conclusions for the d-c motor/generator for the Prototype B hybrid power train are presented here.

a. Interpole Windings. A study of interpole windings for the Minicar d-c motor/generator concluded that the unit must have interpoles for satisfactory operation. The basic reason is that voltage commutation with interpoles is considered the only acceptable method of sparkless commutation for such an application. Without interpoles sparking and rapid deterioration of the commutator results.

b. Compensating Windings. An investigation of utilizing compensating windings in the hybrid power unit showed that compensated windings were not necessary mainly because the transient conditions of these machines are not severe enough to necessitate them. Much of the armature reaction under pole faces can be solved by eccentric pole faces and irregular air gaps for extreme transient conditions.

c. Main Field Windings. An analysis of shunt, series, and compound type machines for Minicar application was performed. A series-wound machine has the most favorable electric propulsion characteristics, the compound machine less favorable, and the shunt machine the least favorable. In contrast, for optimum generating characteristics, the shunt generator is the most favorable, the compound generator next, and the series least favorable. Since one machine cannot conform to the motoring characteristics of a series machine and the generating characteristics of a shunt machine, a compromise is best suited for the Minicar application. This would be a compound machine with a shunt winding to provide a reasonably flat generating field and a series field to provide the desired starting torque.

d. Motor/Generator Specifications. Conversion of the qualitative information into quantitative terms gave the specific electric requirements for the hybrid power train. The procedure used, after specifying an ICE, was to decide upon a desired maximum acceleration schedule and combine this with the road loads of the vehicle. The difference between the power needed to meet this performance and the power available from the ICE alone was the power needed from the electric motor. A complete set of specifications for optimum performance of the motor/generator for the Minicar was thus developed.

Due to the limitations of time and funding it was not possible to engineer a motor to meet all of these specifications. Instead a motor was procured with similar characteristics from Lear Siegler, Inc., Power Equipment Division.

This motor did not meet all of the desired performance criteria. Acceleration was not completely satisfactory due to the heavier than planned weight of the motor and the cycling being heavy on the motor side, thus taking more current from the battery supply than was replenished. Supplied power was less than the rated power.

e. Amplidyne Type Machine. An amplidyne type motor was also investigated for possible use in a hybrid system. The conclusion was that an amplidyne motor is not suited to this power train. The two principal benefits from the amplidyne over a shunt motor/generator are lower control power and increased sensitivity. These factors are overshadowed by the fact that the field control power is not great enough to warrant power amplification of it.

A solid state field current amplifier added to a shunt machine gives better sensitivity than an amplidyne if such sensitivity were necessary. This increased sensitivity obtained by an amplidyne or shunt machine with field current amplifier would, however, be cancelled by the increased mass of the vehicle.

In addition, the amplidyne motor would probably reduce reliability of the power train because of its nonstandard use as a motor/generator.

## 7. Prototype B

a. Description. The first full-scale hybrid vehicle, designated Prototype B, was built during August and September 1969. It was powered by a rated 10 hp d-c electric motor and an ICE of approximately 70 hp rating. The vehicle was initially designed as an all-ICE power train to include a safety frame and plastic protective bumpers. Late in the project a hybrid ICE-electric power train was installed. The power train design

development was severely limited by the short installation time and therefore was considered a zero-order hybrid drive train. The electric power, storage battery, electric controls and ICE carburetion have been continually reworked to obtain a smooth operating system consistent with improved vehicle performance and durability.

The design specifications for Prototype B are as follows:

Overall length-width-height	108"-78"-57"
Weight with three passengers	3350 lbs. <sup>3</sup>
Engine cylinders-displacement cooling	6 - 164 in. - air
Cruise and maximum speed	50 mph -- 70 mph
Cruising range: ICE and all-electric	200 mi. - 2 to 5 miles
Acceleration	0-40 in 10 seconds
Peak hp: ICE and all-electric	40 hp + 25 hp
Seating capacity (97.5 percentile males)	three adults
Estimated fabrication cost: at 2500 vehicles per year	\$3750 per vehicle
at 2500 vehicles per year	\$2500 per vehicle

The vehicle power train components are shown in Figure SI-4.

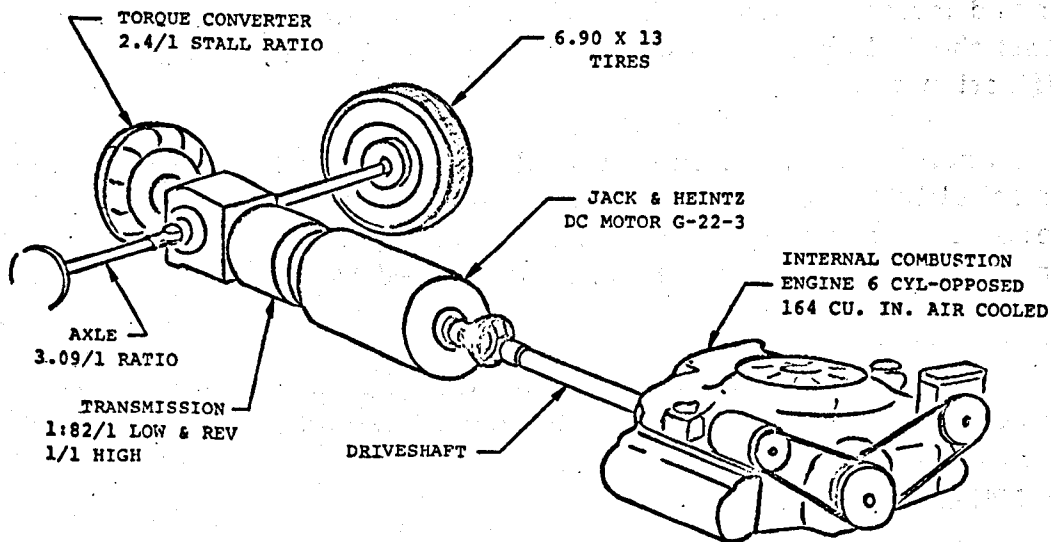


FIGURE SI-4. HYBRID B VEHICLE DRIVE LINE COMPONENTS

The ICE is a Corvair 6-opposed cylinder, aluminum engine with the following specifications:

Bore stroke-displacement:	3.44 x 2.94 in. - 164 in <sup>3</sup>
Maximum bhp:	95 at 3600 rpm
Maximum torque ft. lb.	154 at 2400 rpm
Compression ratio:	8.25:1

The motor/generator is Lear Siegler (Jack and Heinz) Model G22-3, shunt type with the following specifications:

Motor

Voltage:	24 d-c
Current:	200 amps continuous, 600 amps peak
Power:	9 hp continuous
Torque:	52.5 ft. lb. continuous, 105 ft. lb. peak

Generator:

Voltage:	27.5 d-c
Current:	300 amps
Power:	9 KW
Efficiency:	71% to 79%

A 12 gallon fuel tank is located behind the passenger seat and feeds the engine located at the forward end of the vehicle. The drive shaft is connected to the rear torque converter, swing-axle and wheel assembly (modified Corvair types). Integral with the propeller shaft is the rotor of an electric motor-generator which is able to feed energy into or withdraw it from a pack of four lead-acid batteries (of 50 pounds each), according to demand. The batteries are distributed at the rear extremities of the car. This power train should provide between 15 and 25 miles per gallon, depending on the driving habits of the operator and conditions of operation. A maximum of 38 hp is available at the wheels from the ICE, and an additional maximum of 20 hp is available at the wheels from the electric motor. The Minicar will, therefore, be able to exhibit top speeds in freeway traffic of 70 mph or more, and show a good level of agility from 0 to 30 mph in 8 seconds (high gear only) at the maximum design weight of 3350 pounds, including 500 pounds of passengers and luggage.

The Minicar engine, being an opposed six cylinder type is quite vibration-free, possessing inherently more balance than a V-8. The engine will be soft-rubber mounted to reduce transmission of vibration. The electric motor should not cause any vibration noticeable to the passengers because it is an essentially solid and easily balanced system. The transmission should cause little or no vibration for the same reason.



b. System Operation. As shown in Figure SI-5 , the driver can select two modes of vehicle propulsion, an all-electric mode or a hybrid mode. The all-electric mode will open the linear actuated clutch, thereby isolating the ICE from the power train. The electric machine, now acting as a motor, will drive the vehicle for a range of two to five miles maximum. In the hybrid mode the clutch is closed, making a direct mechanical connection between the ICE and electric motor to the rear end. The motor can now operate in a motor or generator state.

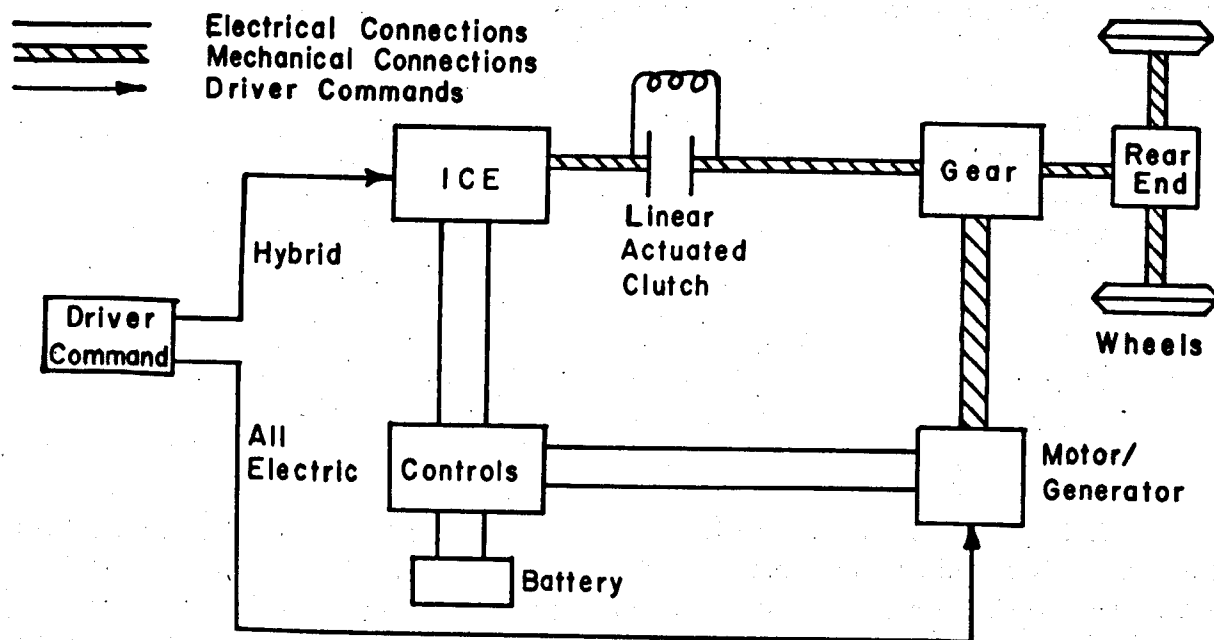


FIGURE SI-5. CONTROL SCHEMATIC

c. Electric Control. The mode (i.e., motor or generator) of the electric motor is determined by the control system shown in Figure SI-5. This control system must perform three main functions:

1. Sense the road load requirements of the vehicle.
2. Compare these power load requirements with what is available from the ICE.
3. Operate and control the electric motor as a motor or generator, dependent on whether the road load is greater or less than the available ICE power at all vehicle speeds.

The first two functions of the control system are accomplished through sampling of the manifold vacuum of the ICE as developed in the hybrid power train.

## 8. Prototype B Tests and Results

a. Hybrid Engine Tests. Qualitative and quantitative tests were conducted on the Prototype B parallel hybrid system.

The ICE used on Prototype B car was altered to run clockwise instead of the original counter-clockwise. No power and fuel consumption tests were run on the engine. It was installed directly in the car and the car power was measured on a chassis dynamometer for evaluation. The power output measurement of the engine via the transmission, final drive and tires is very difficult to determine with this type of test set-up particularly with severe time limitation, as was the case here; therefore, an estimation of the ICE available power had to be made. Power test data of the engine from the manufacturer were used for these estimations.

Road testing showed that the operating range of the electric machine in the generating mode was quite satisfactory. The energy level of the batteries remained at a constant specific gravity. However, the operating range of the motor was quite unsatisfactory, due to a low torque output in the speed range.

To alleviate this problem the right angle gearing was removed from Prototype B, and the electric motor was placed in line with the drive shaft, so that the motor/generator speed is the same as the ICE speed -- 1000 to 3000 rpm.

The electric motor when operating in the motor mode is capable of delivering torque at a faster rate than the ICE. This caused torque pulsations in the power train, which were unsatisfactory for vehicle performance. This problem was eliminated by connecting the electric motor to the ICE through a rubber-u-joint.

Figure SI-4 indicates a transaxle in the rear end of the vehicle. Before modification of Prototype B, which eliminated the right angle drive, low gear in the transaxle had to be used for hill-climbing and fast accelerations. By removing the right angle drive, causing the motor speed range to change from 2790 - 8370 rpm to 1000 - 3000 rpm, the available torque output at any chosen speed was greater. This should allow Prototype B to eliminate low gear and use only the torque converter and final drive of the transaxle.

The engine did not perform to expected power output because of no running-in time and because of lean air/fuel ratio provided by the carburetor. It ran rough and would frequently stall in the car. Some break-in was accomplished by adjusting the carburetor jets.

The power required for level road and the maximum power from the ICE and electric motor are shown in Figure SI-6 for the entire vehicle speed range. The vehicle speed acceleration times are also shown in the Figure. The two acceleration curves represent high gear only and high and low gear transmission operation.

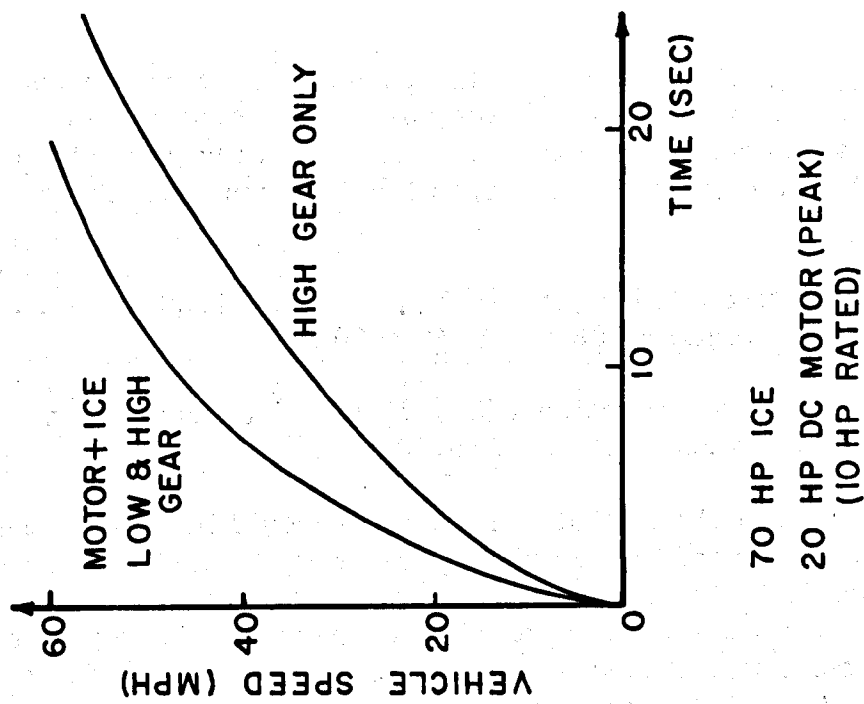
The vehicle performance in high gear only is not acceptable. The automatic transmission needs low gear operation to function in an acceptable manner in city traffic conditions where adequate vehicle accelerations are needed.

Constant speed fuel consumption tests were run at 50 mph. In all-ICE operation fuel consumption was 16.8 miles/gallon (on a distance of 77.3 miles). In hybrid operation it was 17.9 miles/gallon (on 73.5 miles). Additional fuel economy tests at different ranges are needed for more reliable results.

Under all conditions of operation in the all-ICE mode for Prototype B the ICE was overloaded. It appears that this leading condition of the ICE may be due to two factors. First, the ICE is a reversed Corvair engine, which uses a specially ground cam, and additional adjustments may be necessary before the engine will operate optimally. The second factor is simply that because the car is a prototype, exact alignment of all components in the power train was not obtained. Accumulation of these misalignments causes high power losses.

The all-electric mode of Prototype B is presented merely to demonstrate that in the future, the vehicle could operate for a limited range in an all-electric mode. Also, the vehicle will be compatible to an automated electric highway for unlimited range. The battery pack of future production vehicles will have a larger capacity than the pack in Prototype B. Present all-electric capabilities of Prototype B allow for a maximum speed of 25 mph and a maximum range of 2.5 miles.

In summary, the major problem in hybrid operation in Prototype B is that not enough experimentation, investigation, and optimization have been done. The control system is tuned to operate with high transmission gear. When high gear is used, the size of motor and battery pack capacity used in Prototype B is not large enough to accelerate the vehicle from 0 to 30 mph in an acceptable interval of time. If, however, the control system is tuned for low gear, the ICE will have to run at a greater than allowable rpm from 30 to 60 mph. This problem could be alleviated by having the control system automatically tune itself for high or low gear and using a low gear for town use and a high gear for freeway use.



70 HP ICE  
20 HP DC MOTOR (PEAK)  
(10 HP RATED)

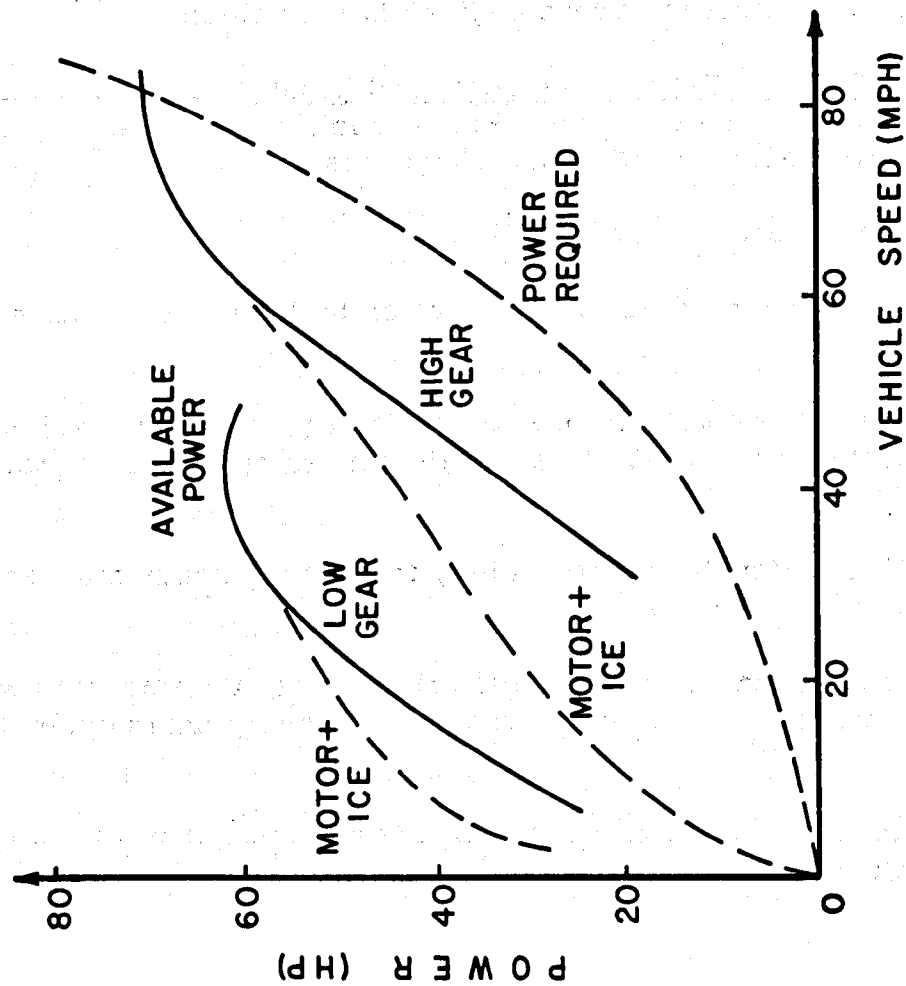


FIGURE SI-6. PROTOTYPE B, HYBRID VEHICLE PERFORMANCE DATA (ACTUAL)

b. Alternate ICE's. Various other small automotive engines were investigated for use in the hybrid power train. This engine search narrowed down to two designs which were then compared with the presently installed air-cooled 6-cylinder engine in Prototype B hybrid vehicle. The two possible engines are:

1. V-4 water-cooled engine (Ford), 104 in.<sup>3</sup> displacement. Power - 83 hp @ 4500 rpm. Torque - 108 ft. lb. @ 2500 rpm.

2. Opposed - 4 air-cooled (VW), 96.6 in.<sup>3</sup> displacement. Power - 65 hp @ 4600 rpm. Torque - 86.8 ft. lb. @ 2800 rpm.

Preliminary evaluation shows that either engine would be better than the present Corvair in respect to the hybrid power train. The VW engine with fuel injection could be better tailored for very low emissions in the hybrid mode. The Ford V-4 is water cooled and provides an improved shape power package in the engine compartment; however, it would require a major design development program to install it in the Minicar.

The test program time requirement of the Prototype B vehicle precluded the installation of either the above engines in the vehicle.

c. D-C Motor Temperature Tests and Results. Field and laboratory testing was performed on the shunt d-c motor in the Prototype B hybrid configuration to evaluate overloading conditions.

The test procedure was as follows:

1. Install appropriate instrumentation to determine armature temperature of the prototype.

2. Run the prototype through a series of stop-and-go cycles to simulate worst case traffic conditions. Measure the temperature of the armature and field windings.

3. After performing these cycles, inspect the commutator and brushes for signs of pitting and wear.

The direct connection of the electric motor to the transaxle will cause transfer of transaxle heat (which reaches 150°C during urban cycles) to the motor.

Test results showed that insulation temperature limits were not exceeded. The maximum temperature of 115°C was well below the allowable 180°C limit.

After the testing program was completed, the electric motor was removed, completely disassembled, and inspected for physical signs of wear or deterioration. This inspection showed that after 3,000 miles of hybrid operation, no brush or commutator wear was observable. The commutator was clean, and brush wear was minimal. In summary, it is concluded that the compound d-c machine with a Class H insulation should pose no definite wear or thermal problems in a hybrid configuration.

It should not be construed, however, that any compound wound machine with this H insulation will satisfactorily operate in any hybrid system. Each system configuration will have to be individually tested until a full production vehicle is manufactured.

d. Conclusions and Recommendations. Primary reasons for developing and implementing a hybrid system in the Minicar is to reduce air pollution and increase reliability thereby reducing overall cost, while providing for dual mode operation and the same overall power characteristics as found in "conventional" automobiles.

A preliminary cost analysis of a system similar to the hybrid system in Prototype B, but installed in a 2500 pound vehicle, has been performed. This system is expected to reduce the emission level, but at the same time, provide performance comparable to an equivalent size car (e.g., acceleration from 0 to 30 mph in 6 seconds) and in addition it will provide for emission-free operation for 5 miles at 25 mph. The electric motor presently used is probably sufficient, although some modifications will be required, such as addition of a few series turns to improve the motoring characteristics, inclusion of forced air cooling, and possible modification to allow reverse of operation.

The present system utilizes a 24 volt 190 AH pack. To improve this system the battery capacity should be doubled. This will require approximately 320 pounds of lead-acid batteries. Solid state components should be used for controls, giving a system which is reliable, safe and provides for regenerative and/or dynamic braking.

A more powerful electric motor and a more efficient power train than the mechanical drive train is recommended. Performance characteristics are shown in Figure SI-7. The electric motor power is shown for 30 hp and the low speed ICE power is increased because of higher transmission efficiency. The ICE can operate at high gear only with no shift needed. If a direct drive can be built with the electric motor providing the high torque values needed at the low speed portion of the vehicle velocity operation, a more efficient drivetrain can be obtained. Final study conclusions recommend 40 hp ICE and 40 hp electric motor in order to further reduce exhaust emissions.

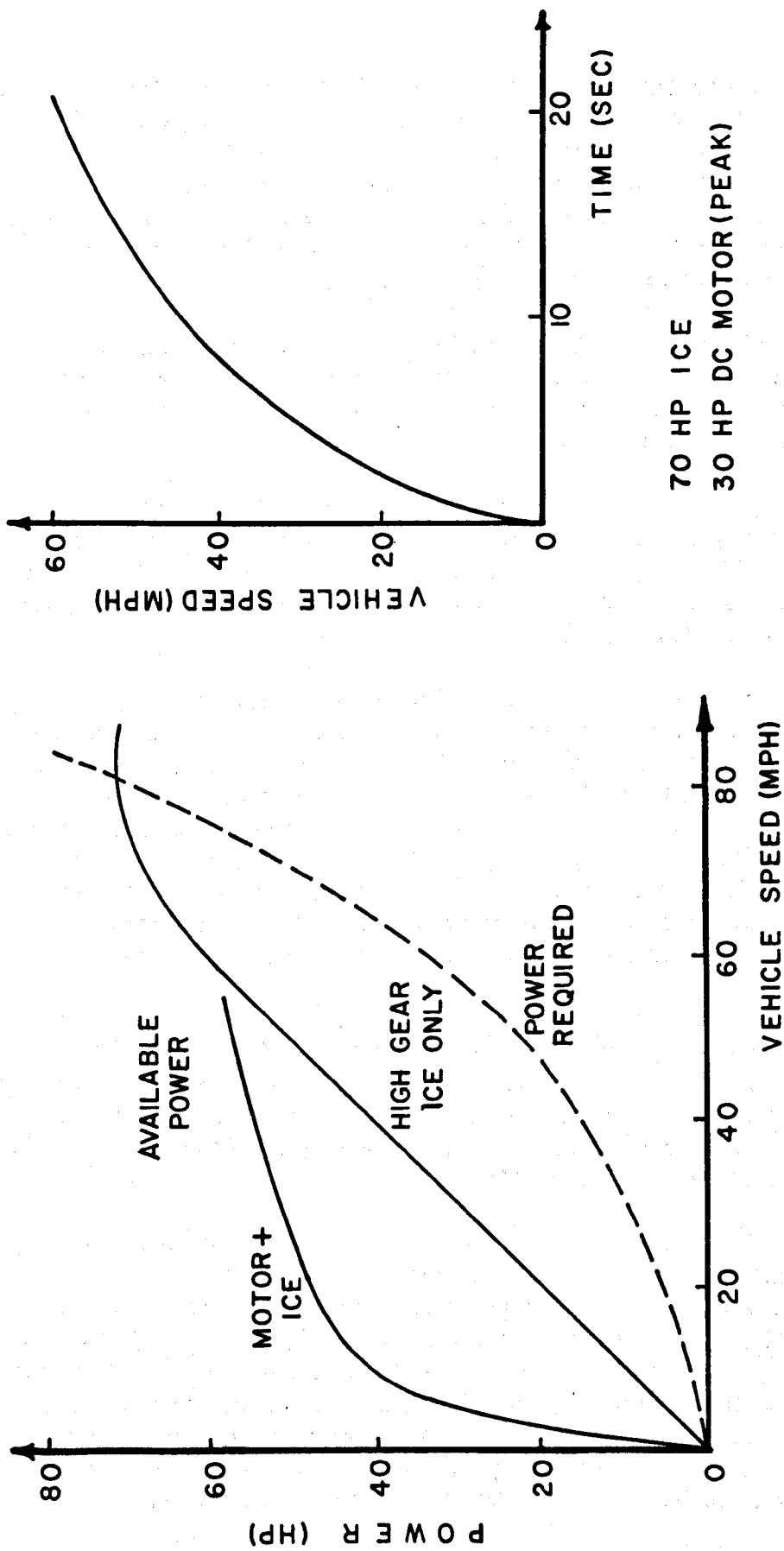


FIGURE SI-7. PROTOTYPE B, VEHICLE PERFORMANCE DATA (PROPOSED IMPROVEMENT)

Further testing of the overall hybrid system along with a complete trade-off analysis should be done to further verify these recommendations.

## 9. Vehicle Emissions

a. Tests. The Prototype B vehicle was tested and evaluated for exhaust emissions. The procedure for testing consisted of prescribed sequences of vehicle operating conditions on a chassis dynamometer. The exhaust gases generated during vehicle operation were sampled continuously for specific component analysis through an analytical train. The basic test was designed to determine hydrocarbon, carbon monoxide and oxides of nitrogen concentrations while simulating an average trip in a metropolitan area.

Four power train arrangements of the Prototype B vehicle were evaluated. These set ups, all with a 6 cylinder, 164-in<sup>3</sup> displacement, air-cooled ICE, include the following:

1. Hybrid Power, Rich engine-24V, d-c motor drive  
Carburetor: low speed fuel circuit set rich, main fuel circuit set lean, no fuel enrichment during acceleration.
2. All ICE Power, No electrical drive  
Carburetor: low speed fuel circuit set lean, main fuel circuit set lean, fuel enrichment during acceleration.
3. Hybrid Power, Lean engine-24V, d-c motor drive  
Carburetor: low speed fuel circuit set lean, main fuel circuit set lean, no fuel enrichment during acceleration.
4. Hybrid Power, Lean engine-48V, d-c motor drive  
Carburetor: low speed fuel circuit set lean, main fuel circuit set lean, no fuel enrichment during acceleration.

b. Results. Exhaust emissions of hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxide (NO) for the gasoline-electric hybrid power train of the prototype vehicle were measured. The hybrid power emissions were compared with those generated by the same vehicle, with only ICE. Even with the power train in essentially "zero-order" hybrid design stage, there was reduction in the exhaust emissions. HC was reduced 50% from a normal ICE operation and 17% from a lean air-fuel ratio ICE. CO reduction was approximately 15%. NO and CO could be minimized with extremely lean air-fuel ratio that should be allowable with additional hybrid power development. Carburetion, ICE intake system and electrical controls were modified to allow extremely lean air-fuel ratios.



c. Recommendations. These first exhaust emission tests conducted on Prototype B have shown some emission reduction for the hybrid compared to all ICE power trains: but, the reduction of 17% for HC and 15% for CO with an increase of 8% of NO represents only a slight indication of what can be achieved with an ICE-electric hybrid power train. More substantial reductions can be made by the following modifications:

- Raise the ICE air-fuel ratio to 18 or more
- Operate ICE at higher top speed
- Use smaller displacement ICE
- Use lower compression ratio (7 to 1)
- Use retarded spark-advance timing
- Provide adequate electrical power to completely unload the ICE during vehicle acceleration, and remove ICE enrichment pump.

These changes can be made without impairing overall drive train performance because of the ability of the electric motor to carry the ICE through periods of stumble, acceleration, starting, etc.

The hybrid power train with design alternatives for pollution control is shown in Figure SI-8.

#### D. Mechanical Features\*

This section on the Minicar's mechanical components includes primarily the design, construction, testing and analysis of Prototype B. In turn the design of B was based upon the results of its predecessor, Prototype A, details of which may be found in the Documents on Prototype A.

Although far from a production vehicle, Minicar Prototype B has been used to answer some of the fundamental feasibility questions in ride, handling, performance and suspension areas.

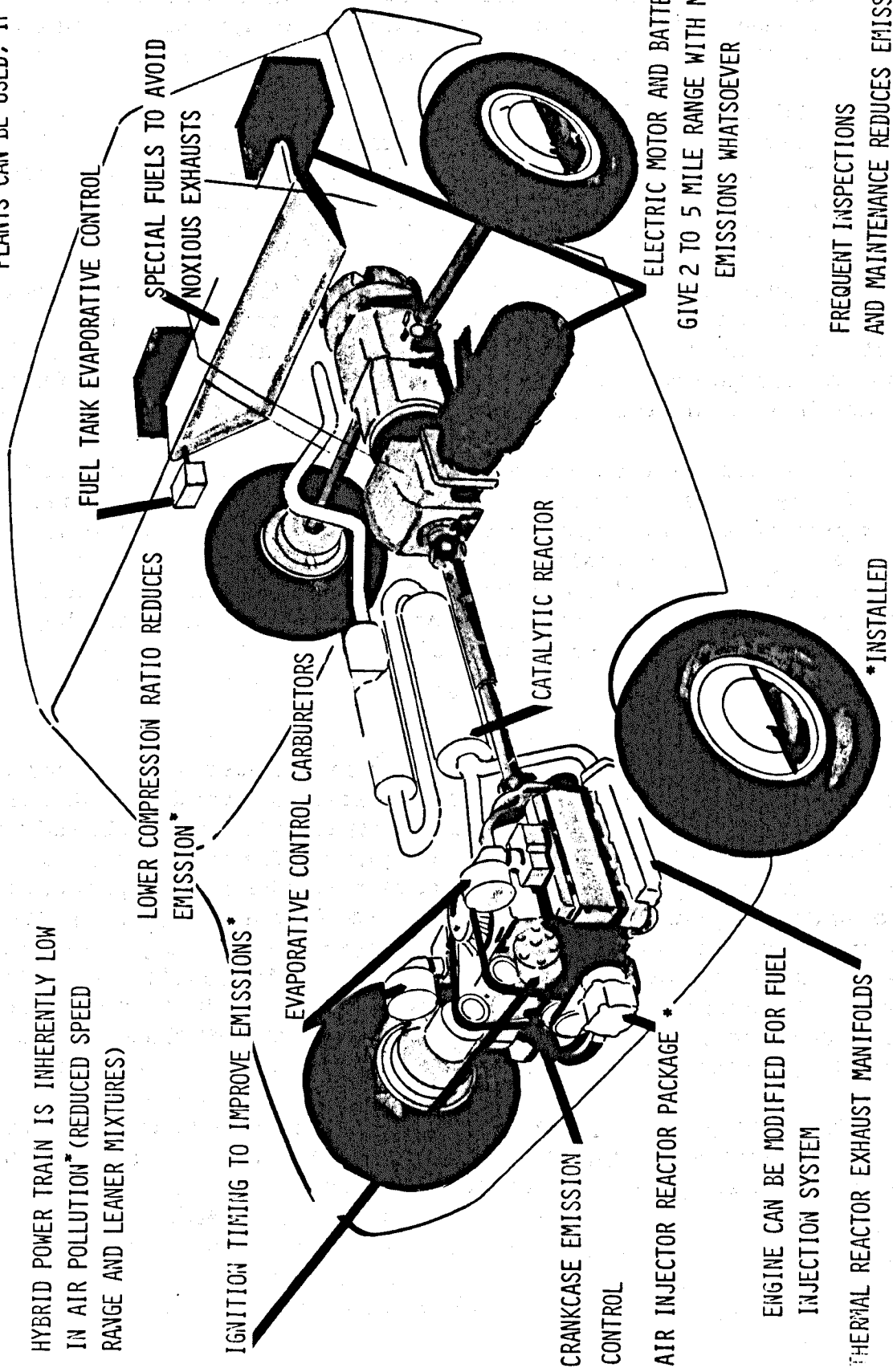
##### 1. Steering

The experimental chassis used a rack-and-pinion steering gear which gives the driver precise wheel control; however, under certain rough road surface conditions, the feedback through this type of linkage is excessive and requires damping. The other choices for steering are worm and sector (typical of domestic cars) or the recirculating ball type. The worm and sector has the advantage of good road feel and fair precision, but tends to wear more rapidly and is in need of more frequent adjustment. The recirculating

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\* See reference[T-1a].

STEAM, TURBINE AND OTHER POWER PLANTS CAN BE USED, IF DESIRED



HYBRID POWER TRAIN IS INHERENTLY LOW IN AIR POLLUTION\* (REDUCED SPEED RANGE AND LEANER MIXTURES)

LOWER COMPRESSION RATIO REDUCES EMISSION\*

IGNITION TIMING TO IMPROVE EMISSIONS\*

EVAPORATIVE CONTROL CARBURETORS

CATALYTIC REACTOR

CRANKCASE EMISSION CONTROL

AIR INJECTOR REACTOR PACKAGE \*

ENGINE CAN BE MODIFIED FOR FUEL INJECTION SYSTEM

THERMAL REACTOR EXHAUST MANIFOLDS

\*INSTALLED

ELECTRIC MOTOR AND BATTERIES GIVE 2 TO 5 MILE RANGE WITH NO EMISSIONS WHATSOEVER

FREQUENT INSPECTIONS AND MAINTENANCE REDUCES EMISSIONS

FIGURE SI-8. HYBRID POWER TRAIN AND DESIGN ALTERNATIVES FOR POLLUTION CONTROL

ball type of arrangement was excluded because of its initial cost. Consequently, at present the choice is the rack-and-pinion type using a suitable hydraulic or other type damper to prevent excessive feedback.

Initial testing of Prototype A showed an excessively large turning radius due to heavy anti-ackerman characteristics. Severe scuffing of the inside front wheel, in conjunction with excessive camber changes, resulted in considerable understeer and a high level of acceleration of the front suspension under rebound.

To correct these failings a standard Corvair (1968) front suspension was installed with modifications to the steering assembly to yield the proportionate amount of ackerman characteristics. This change has resulted in an effortless turning circle of 30 feet outside to outside, and has furthermore stabilized straight-away tracking capability of the car.

Subsequent trial runs showed that the car has a highly dampened ride with very good steering response, is mildly sensitive to rear-wheel drift on hard surfaces, but gives very quick warning. On rough terrain and under heavy abuse the chassis remains distortion-free, except for spring-shock towers (Corvair) deflecting towards center line of car. This is due primarily to insufficient bracing in that area and to the poor weldability of the metal used for the Corvair frame members.

## 2. Braking

The Minicar braking system is similar to that used on most conventional American passenger cars. Drum brakes were selected over disc brakes in view of their relative economy and equal braking capacity for the weight and speed of the Minicar. The four-wheel hydraulic-type service brake system can stop the car at a deceleration rate of 0.75 g or higher. The master cylinder is a dual or split type, and is connected to separate front and rear wheel slave cylinders through steel tubing and flexible hoses. Internal expanding drum brakes are used both front and rear. Sixty percent of the braking effort is generated at the front wheels, forty percent at the rear. Failure of either the front or the rear brake hydraulic system is indicated by the appearance of a red light on the driver control unit.

The parking brake system is mechanical, operates on the rear wheels only, and is actuated by a separate foot pedal/ratchet mechanism located at the extreme left side of the passenger compartment.

### 3. Suspension

a. Front Suspension. On the experimental chassis and in the design of the Prototype A chassis, the wheels are all independently sprung. Independent front suspension is a necessity on a vehicle with proportions of the Minicar (73" wheelbase, 62" wheel track). For the prototype chassis the front suspension components of the Corvair were chosen, principally because they are analogous to all domestic compact car components, and consist of unequal length "A" control arms, mounted with coil springs and hydraulic shock-absorbers. Changes from the standard settings used on the Corvair consisted of decreasing the caster angle due to higher frontal loadings on the prototype chassis as compared to the Corvair, and of an increased rate of camber change between bound and rebound in order to introduce a slight amount of understeer and generate the feeling in the driver of driving a heavier vehicle.

b. Rear Suspension. The choice for the type of rear suspension on the prototype chassis was dictated by factors not connected with the chassis design as such. By integrating the results of the other task efforts for the design of the Minicar, it occurs that there is little room for a mechanical transmission, except in the rear, aft of the passenger compartment, and virtually in line with the center line of the rear wheels. This combination transmission and differential (called transaxle) forces the wheels to be sprung independently. Due to the height and weight of the components, a rigid or live axle configuration incorporating the transmission would give an unfavorable sprung to unsprung weight ratio and therefore an unacceptable ride.

This method of suspension, via transaxle and independent wheel movement, is by no means the optimum. Cost is high, and the only possible unit currently manufactured domestically (Corvair) is being discontinued. The other (Pontiac Tempest) is obsolete and procurement is highly questionable. For the prototype, Pontiac parts were used although a live axle and a specially designed gear box (for reverse) with torque converter would reduce the unnecessary complexities of the independently sprung transaxle. Structural configurations in the chassis are such that virtually no changes would be involved, other than the change of components in question. In both cases, springing is by coil spring with hydraulic shock absorbers and wheel movement is controlled by trailing control arms.

Road testing of Prototype A showed a harsh ride, with severe undampened bottoming of the rear suspension. It was therefore decided to change rear suspension, spring and shock combination to a composite unit of concentric shock mounted springs with a 60% increase of spring rate, and an increase of jounce travel to 3". Even though no ultimate jounce stop is installed, bottoming of this configuration has not occurred despite severe application over rough terrain.

Road testing of Prototype B exhibited that due to the high sprung-unsprung weight ratio (12:1), the ride is easily comparable with that of large heavy cars, and is virtually free from pitch or lean associated with small cars. Handling qualities under normal conditions are similar to those of a medium size compact car. Handling under severe side load conditions is below what could be expected. Rear end break-away is gradual with ample warnings. Front end break-away is sudden, and an unprepared driver can over control severely. Once rear wheel break-away occurs, it is self-dampening. The vehicle remains flat and exhibits excellent rollover resistance. Rear suspension characteristics under these conditions show none of the acute "windup" and pitch of which swing-axle systems are accused.

The construction of the Prototype B has proven amazingly rugged and safe. On a prolonged test drive the car was taken into a severely tightening turn at a speed in excess of the maximum speed warranted. The outside wheels lost traction and the vehicle consequently rotated on its own vertical axis several times. It was eventually brought back to rest by a concrete curb. Partial collapse of front end components, as per design, was experienced. Except for considerable misalignment of the front wheel geometry and a broken engine forward mount, no significant damage was incurred, nor were the occupants at the time aware of the severity of the deceleration.

#### 4. Controls

Basic control layout has been predicated on the importance of convention as opposed to uniqueness for the benefit of the operator. The steering wheel is mounted on a conventional, collapsible steering column, while the possibility of replacing the steering column with a flexible rotary shaft is currently under investigation. The other manual controls include a gear selector (forward, neutral, reverse), a turn signal indicator, a windshield washer/wiper switch, a radio control volume knob, and an emergency flasher button. Foot controls include an accelerator pedal and a brake pedal. All manual controls are incorporated in a driver control unit and are adjustable for varying driver sizes.

The seat has been fixed with the seat frames integral with the Minicar interior shell. To adjust for individual size the driver gets in the Minicar and moves the steering wheel to the position most comfortable for him. The toeboard is electrically adjusted into the selected position.

Since the driver cannot respond to a problem with the Minicar by repairing the car himself, there is little justification in providing him with qualitative display information relative to the Minicar sub-systems. Therefore, instrumentation is as simple as possible including only speedometer, a trip odometer, turn signal indicator and a fuel indicator of conventional, commercial design.

## 5. Lighting

In general the Minicar prototypes are equipped with a conventional 12-volt automotive electrical system. The only major modification would be the use of a solid-state ignition system so that its performance may be evaluated in terms of increased life for points and spark plugs. All Minicar lamps will be operative for a minimum of 15 minutes after the motor is turned off.

The Minicar prototype lighting will meet the existing Federal standards and is being designed to SAE recommendations. Consideration was given to having the entire lighting system on when the ignition system is on so that no separate light switch would be provided. This would be an important safety characteristic, since many accidents occur when drivers have not turned on lights when driving at dusk or in rain, snow or fog.

The driver control unit contains illuminated instruments for night driving and signal lights which are visible in any interior ambient lighting conditions including bright daylight. A compartment interior light is provided and operates when either door is opened supplying compartment illumination of 15 to 30 candle power.

The Minicar is equipped with headlights, front and rear turn indicators, red taillights, stop lights, license plate light, backup lights and side running lights. The headlights are provided with a high-beam control switch. The turn indicator lamps are equipped with a self-cancelling manual switch mounted on the steering column. The stop lights are actuated by a brake pedal switch. The Minicar is also equipped with an emergency flasher unit which meets SAE recommended practice. Two red reflectors are positioned on the rear side panels and front side panels.

## 6. Heating and Air Conditioning

Two types of heating systems have been investigated: a gasoline fired heater and a conventional ducted hot air or blower system. For best fire resistance and system component reliability, the hot air system has been utilized in the Minicar. The interface between the heating and air conditioning system has not yet been determined, but a single manual control will operate both systems.

The Minicar heating system is capable of raising and maintaining the compartment ambient air temperature to 85°F after an initial 15 minute warm-up.

A defrosting system is integral with the heater and meets the SAE standards for both windshields and backlights.

The air conditioner of the Minicar is of conventional automotive type, capable of sustaining a compartment air temperature of 60°F after initial start-up period (15 minutes). The optimum temperature for driver performance is 65°F and optimum temperature for driver comfort is about 74°F. Manual control of the air conditioner will be provided from the driver's position.

The Minicar is provided with air intake and exhaust ports which under normal running conditions provide the passenger compartment with ambient air at the rate of 5 to 10 cubic feet per minute.

#### E. Human Factors\*

##### 1. Safety

Passenger safety is a Minicar design parameter of prime importance. Current U.S. Government automobile safety standards have been utilized as a minimum requirement. However, a concerted effort has been made to exceed these standards within reasonable economic and practical considerations.

The principal Minicar safety features are shown in Figure SI-9. The basic safety aspect of the Minicar body configuration consists of the following relationships between the passengers and the vehicle: the passengers are located within the perimeter frame described in section B above. To this frame are fixed the individual passenger restraint systems. The entire passenger compartment is surrounded with energy absorbing, crushable foam, materials. An impact of the Minicar in any horizontal plane means that the energy absorbing structure collapses attenuating the forces acting on the passengers. The perimeter safety frame keeps the passenger compartment intact, and the restraint system keeps the passenger within that compartment.

The amount of energy absorbing material which surrounds the compartment determines the force level on the passenger restraint system. Trade-off studies have been made in terms of various components of the safety system, which include the type of energy absorbing, crushable materials and the various available types of passenger restraint systems.

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\* See references [T1a,d,j and k].

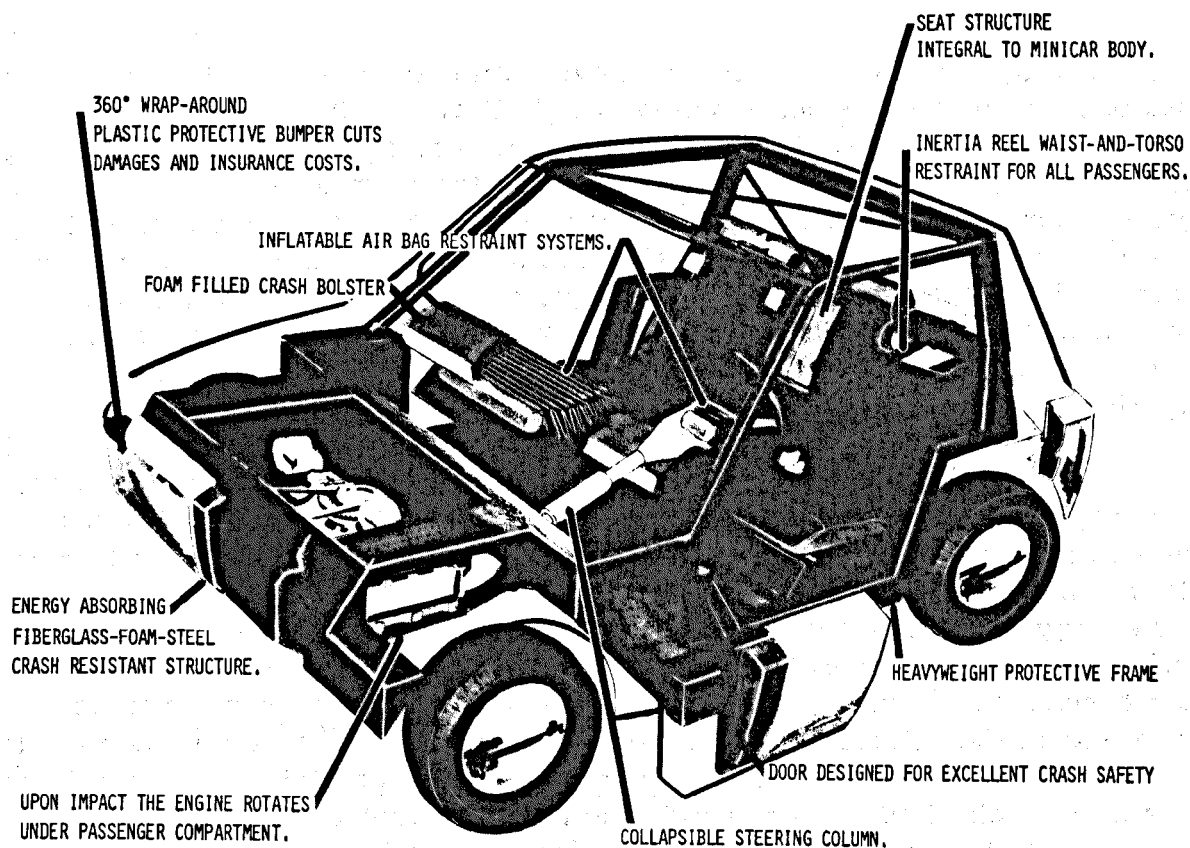


FIGURE SI-9. MINICAR SAFETY CONSTRUCTION

a. Passenger Restraint System. Various types of commercial restraint systems which were designed both for aircraft and automotive use were examined. These include the standard separate lap-and-shoulder harness (military aircraft type), and a seat-and-shoulder harness which is mounted on the perimeter frame which is integral to the fixed seat configuration. The standard 1969 passenger car units require a separate latch and adjusting element for each belt. This presents a real problem for use in a Minicar because large numbers of people will be driving each Minicar and each driver would have to readjust the restraint system for his body size. The military four point system offers perhaps the highest degree of restraint, since it incorporates dual shoulder harnesses, but it is also the most cumbersome, since four separate belts must be latched together by the passenger. Two of the belts used require individual adjustment. The inertia reels of this military system would also need to be redesigned to lock up at lower forces for automotive use, since in aircraft use they lock only in a 2-4g forward acceleration.



The system chosen in the prototype Minicars is a new design and consists of both an inertia-reel mounted seat belt and an inertia-reel mounted single shoulder harness. The two belt ends are fixed together on a pivoting latch plate. When the system is not in use, the inertia reels retract the belts against the seat surface. To engage the restraint system the passenger simply pulls the belts across himself and latches the system. No adjustment is required, and the passenger is still free to move about even with the restraint system latched. The system locks when the passenger receives an acceleration of 0.5g. The belts themselves have a maximum stretch of only 10".

b. Energy Absorbing Front End. The entire front end of the Minicar is an energy absorbing structure. The general configuration consists of a solid monolithic member which is positioned across the entire front of the Minicar. This member is suspended on elastic shock mounts from the remainder of the body energy absorbing structure. In a typical low-speed (1 to 3 miles an hour) impact the energy absorbing front end deflects like a conventional steel bumper. At higher impact speeds the front end transmits the force to the rest of the Minicar structure and then begins to absorb energy as it is crushed. A feasible construction technique includes a rigid reinforced fiberglass plastic shell filled with rigid, high density urethane foam. This would be mounted to the Minicar with an "O" ring type rubber gasket around the periphery of the Minicar nose section.

c. Roll Structure. Two methods by which a roll structure could be included in the Minicar for passenger protection were analyzed. The first method is to reinforce the top so that it remains intact in the roll over condition. This requires that the top be heavily reinforced with fiberglass or metal hat sections which would be bonded in place. The alternative to this configuration is the fabrication of a separate roll bar which is not fixed to the Minicar top but is an extension of the Minicar perimeter chassis. The roll bar was selected principally for reasons of ease in fabrication.

d. Peripheral Bumpers. The Minicar body is surrounded with a peripheral bumper from belt line to bottom of body. This bumper serves two purposes. Its first function is to prevent minor damage to the Minicar such as scrapes and gouges from other car doors or other cars bumping into the Minicar at low parking lot speeds. In this way the peripheral bumper acts in much the same way as conventional fore and aft car bumpers. Its second and most important function is that it constitutes a crushable structure in the case of high-speed impacts. Determination of the most appropriate crushable material is still under way. Various combinations of materials will suit the purpose. One technique is a peripheral bumper skin formed from flexible

polyester resin. This skin covers rigid urethane foam. The unit is permanently installed on the fiberglass body surface. Another configuration is that of a thick (about 1" ) , high-density flexible urethane pad with a fiberglass backing. This structure is in turn backed up with a rigid urethane foam and fixed to the fiberglass body skin. A third alternative utilizes a thin flexible urethane pad over the fiberglass door skin. The body section shape is modified in this configuration to form the bumper contours. The doors in all these cases are filled with rigid urethane foam.

Additional safety features to be incorporated in the Minicar are the following, some of which are not yet completed in design:

- (i) Provision to swing engine down and under the passenger compartment in a high speed collision
- (ii) Head restraint
- (iii) Protection of fuel tank against impact
- (iv) Interior padding
- (v) Quick-inflation air-bag restraints
- (vi) Extendable bumpers designed to reduce peak collision loads
- (vii) Major concentration of mass (such as engine and batteries) as far toward front of vehicle as practical.

## 2. Ride and Handling Characteristics

In terms of dynamic response, the human body is, in the mechanical sense, a complex nonlinear, dampened, multi-mass system. For this reason, it is difficult to place real numbers on the Minicar ride in terms of passenger comfort at this stage of development. The "ride" qualities of any vehicle are also very subjective and can best be determined by comparison. The comparison of ride of the Minicar test-bed vehicle with ride of a conventional car is the basis for determining ride parameters.

Ride and handling of the Minicar was tested in a preliminary experimental chassis, driven all-electrically, simulating actual weight and mass conditions. The question of handling and directional stability was answered satisfactorily. In this preliminary ride-and-handling experiment it was found that a high polar moment to mass ratio, in conjunction with full independent suspension all around, gave not only good high speed directional stability, but contributed to good steering and cornering characteristics. The actual ride over normal pavement conditions can be favorably compared with a standard

domestic compact, although on certain washboard surfaces the extremely short wheel-base made itself known by producing a certain amount of chop. In the design and layout of the prototype A and B chassis, therefore, considerable effort was made toward eliminating that chop by the following:

- (i) Increasing the diameter of the wheels from 12" to 13"
- (ii) Increasing the cross section of the tires from 145 mm to 185 mm
- (iii) Increasing the suspension travel from 3" to 4-1/2"
- (iv) Decreasing the spring rate from 150 lbs. to 137 lbs./in.

The reduced wheelbase of the Minicar results in an inside turning radius of 14 feet, which is 25% less than that of a standard full-size American car. Stability against gust loading, usually an adverse feature of compact cars, is at least as favorable as for full-size American cars. Roll over stability is favorable by virtue of the relatively wide stance (63 inches) of the Minicar. However, pitch sensitivity is inherently somewhat adverse for the Minicar in virtue of its reduced wheelbase. This sensitivity has been minimized by increasing the car's polar moment of inertia as much as possible through judicious placement of engine and batteries.

The Minicar suspension effectively cushions the passenger module from road shocks and vibrations. With the current values for the vehicle mass and spring rates, the suspension's frequency without shock absorbers is about 10 cps. With shock absorbers the resonant frequency drops to between 5 and 7 cps. Because of the low sensitivity of passengers to this frequency range, and because few roads will have undulations at a rate corresponding to this frequency, the suspension should seldom cause discomfort by virtue of resonance.

In summary, the roadtesting of the Prototype vehicles as reported in the section of "Mechanical Features" showed the Minicar to possess very good steering response and a highly dampened ride. Under normal conditions the handling qualities proved to be similar to those of a medium size compact car.

## F. Summary

### 1. Basic Vehicle Specifications

Following are the basic specifications for the Minicar vehicle developed by this Study:

## Dimensions

Length	108 inches
Width	78 inches
Height	59 inches
Seating Capacity	3 adults
Weight with three passengers	2,750 to 3,500 pounds

## Engine

Cylinders	6
Displacement	164 cu.in.
Cooling	forced air

## Speed

Cruise	50 mph
Maximum	70 mph

## Cruising Range

Internal Combustion Engine	200 miles
Storage Battery Only	2-5 miles

## Acceleration

0-40 mph in 10 seconds

## Peak Horsepower

Internal Combustion Engine Only	40 hp
Battery Powered Motor Only	40 hp
Combined	80 hp

## Emissions

Hydrocarbons	0.4 grams per mile
(2 estimated for current prototype)	
Carbon Monoxide	4 grams per mile
(16 estimated for current prototype)	
Oxides of Nitrogen	0.4 grams per mile
(3 estimated for current prototype)	

Safety Features: Energy-absorbing fiberglass-foam-steel peripheral bumper and body; heavyweight protective frame and rollbar; "must use" inertia-reel waste and torso harness.

Comfort and Convenience Features: 61-inch seat with 38-inch headroom and 40-inch legroom; automatic transmission; heater and air conditioner; radio.

## 2. Recommendations for Future Testing

Development of low gear operation in automatic transmission is necessary to permit better operation in city traffic.

Additional fuel economy tests are required at lower constant speeds.

Further testing of Prototype B is recommended for improvement in the all ICE mode of operation.

Additional development and testing is desirable for all electric vehicle operation.

Evaluation of alternate internal combustion engines, specifically a V-4 water cooled Ford engine and an opposed 4 air-cooled VW engine, to improve hybrid operation and to further reduce exhaust emissions.

A more powerful electric motor should be evaluated to increase power train efficiency at low vehicle speeds.

Modifications to the ICE air fuel ratio, displacement, compression ratio and timing to reduce exhaust emissions.

Investigation of the substitution of a centrifugal or electrical clutch for the torque converter is recommended in order to lower manifold depression at idle and increase volumetric efficiency.

Further development and testing of a combination of the Prototype B parallel system with the series system for increased efficiency and emission reduction.

Experimental validation is desirable on the compounded driver controls for the ICE and the additional electromotive power source for performance and durability.

## Technical Supplement S-II

### CONCEPTUAL DESIGN OF HYBRID POWER TRAIN CONTROL

#### A. Objective and Scope of the Study

The objective of this study has been to develop a design procedure for the control system of a hybrid power train consisting of a d-c motor/generator, an internal combustion engine (ICE) and a torque converter. Initially it was planned to analyze both steady state and transient state performance within this task. The control system for steady state was designed and its development and equations were presented in reference [T-2]. However, time did not permit sufficient work on the transient state to warrant its discussion herein. Accordingly this section covers only the design work completed on steady state performance.

The power train arrangement is displayed in Figure SII-1.

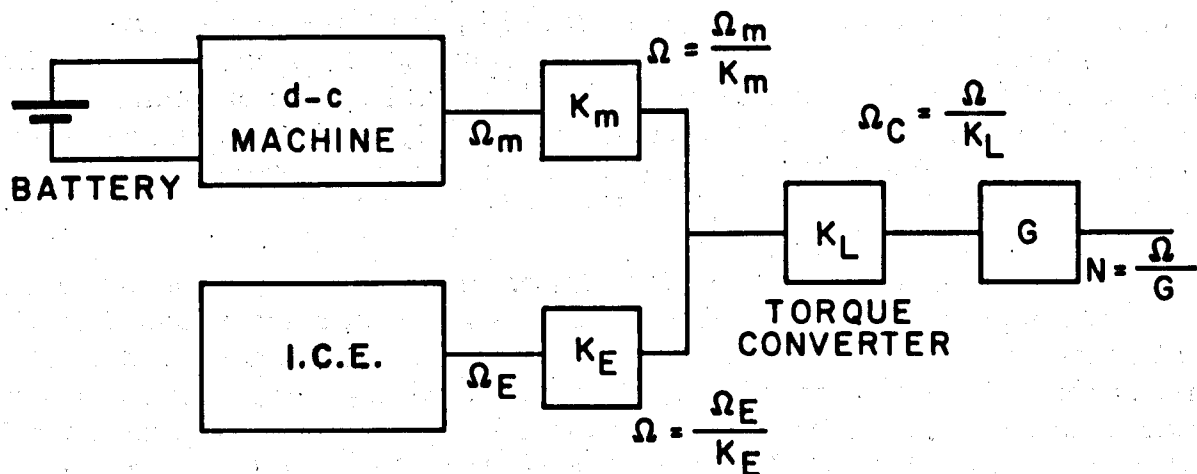


FIGURE SII-1. BLOCK DIAGRAM OF HYBRID SYSTEM

Total load power of the propulsion system equals the sum of ICE power and d-c machine power. The quantities available to control the power are the fuel input to the ICE and the field current in the d-c motor. As a first step in the design of the system, it is desirable to establish the relationship between the control quantities and the vehicle speed in steady state for a specified road load. The method developed in this study enables the effect of various gear ratios and torque converter characteristics to be taken into account, and it can be applied to studies of both shunt and compound d-c motors.

## B. Conclusions

Findings of this analysis can be summarized as follows:

1. The preliminary comparative study of shunt and compount motor for Minicars indicates that while a compound motor offers some small advantages over the shunt from the control standpoint either would be satisfactory.

2. It is desirable to arrange the control in such a way that the battery will charge at the lower range of vehicle speed including standstill and also for a range of cruising speeds. At the top of the speed range the battery will discharge so that the d-c motor/generator, acting as a motor, will complement the ICE in achieving these vehicle speeds.

3. This operation cannot be accomplished with field current control alone. A change in fuel input of at least two to one will also be necessary. It appears that the results would be achieved by the following scheme: floor accelerator pedal mechanism first weakens the d-c field from a nominal value to half that value, and then increases the fuel input from minimum setting to twice minimum at constant field current. Finally the mechanism weakens the d-c field from one half to one quarter the initial value at constant fuel input.

A somewhat more detailed description of such an operation appears to be in order. Figures SII-2 and SII-3 show the variation of current to and from the battery and control settings vs. engine speed for the described control arrangement. A vehicle speed scale is also included which, because of the torque converter, is not linearly related to the engine speed. Mathematical derivation of the information in these figures is included in Reference T-3. The sequence of operation begins with the vehicle in a standstill position on a level road. To hold it stationary, a brake torque must be applied (marked as 100% on Figure SII-3). Figure SII-3 indicates that the battery is charging at a rate of 100 amperes at that time. When the brake is released, the brake torque drops to 0% and the vehicle accelerates to about 13 mph and an engine speed of 1050 rpm (region A in Figure SII-3). The battery is now discharging at about 20 amperes. Assume the accelerator pedal is then depressed so that we enter region B of Figure SII-3. The field current is thus weakened and the d-c motor delivers more torque. When the point a is reached, the engine speed is 1550 rpm and the battery is discharging at 95 amperes in steady state. If the accelerator is further depressed, we enter region C where the field current remains constant and the fuel rate to the engine is increased. At the end of this region (point b on Figure SII-3) the engine speed is 2150 rpm and the battery is again charging at about 100 amperes. This is because at this fuel rate the

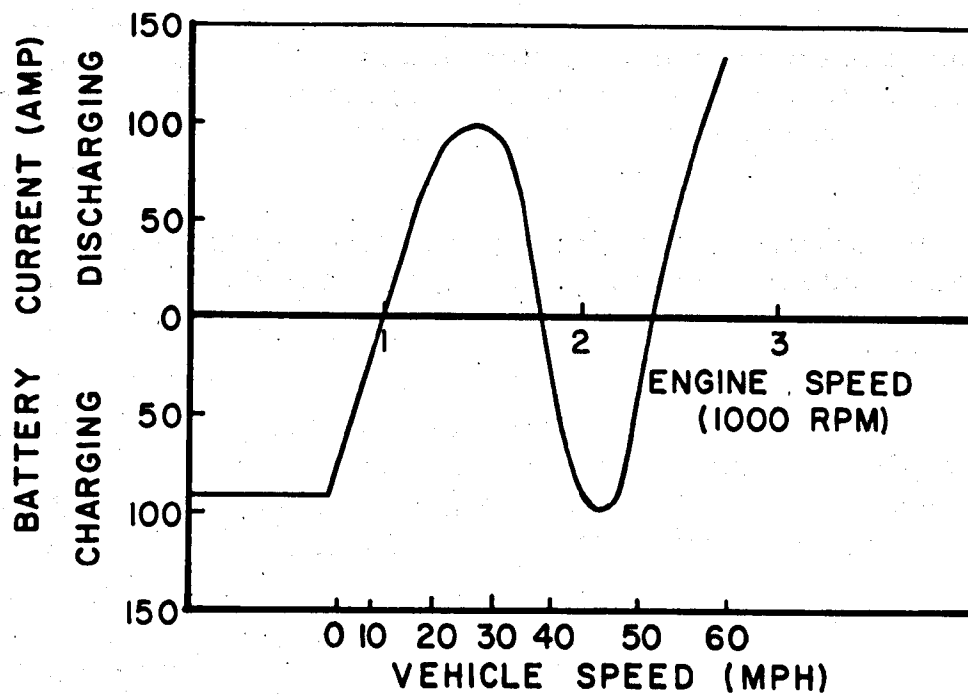


FIGURE SII-2. CURRENT VARIATIONS VS. SPEEDS

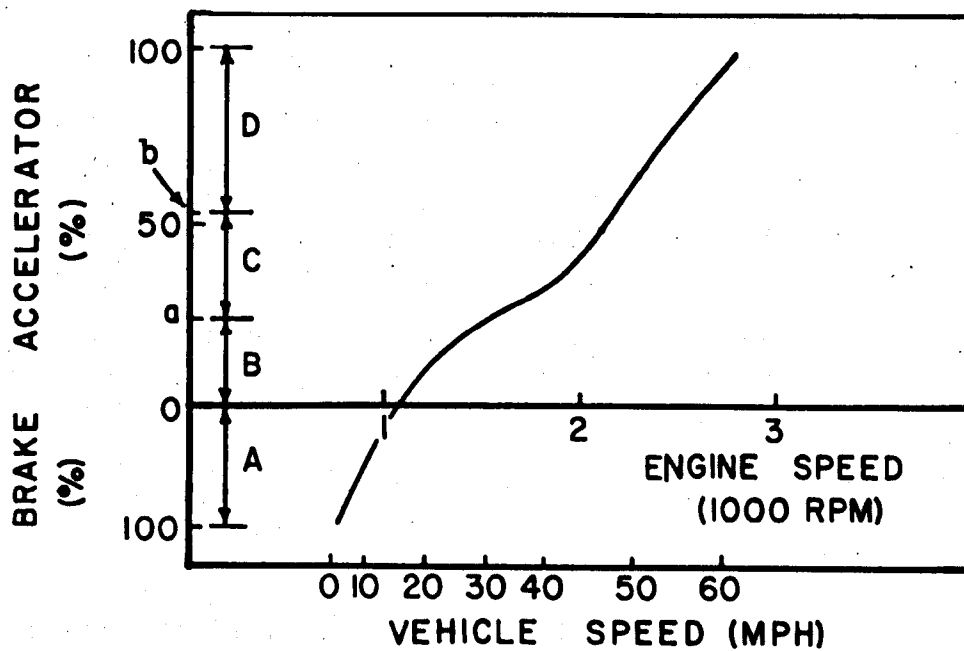


FIGURE SII-3. CONTROL SETTINGS VS. SPEEDS



engine develops more torque than is necessary to overcome the road load, while the extra power charges the battery. Finally, if the accelerator is depressed still further, we enter region D on Figure SII-3, where the fuel remains constant and the d-c motor field is further weakened. At the end of this region (100% accelerator depression) the engine speed is 2750 rpm, and the vehicle speed is 60 mph. The battery is discharging at a rate of 134 amperes.

In summary, a charging region at low speeds will keep the battery charged for city driving and a charging region in the 40-50 mph range will keep the battery charged during open road driving, thus satisfying the control scheme objectives.

It is recommended that this study of steady state be supplemented by an analysis of transient state performance during acceleration and deceleration. Physical development, testing and evaluation should then be pursued to optimize the system.

## Technical Supplement S-III

### SYSTEM OF TERMINALS

The System of MTS terminals is specified by the locations and sizes (number of parking spaces) of the terminals. These should be based on the following factors:

- (i) Demand distribution;
- (ii) System of terminals (locations and sizes of other facilities);
- (iii) Access conditions (network configuration, traffic flows, etc); and
- (iv) Site characteristics (size, shape, character of the surroundings).

While items (iii) and (iv) depend on the specifics of each location and little can be generalized about them, item (ii), as a function of item (i), requires a fairly extensive theoretical analysis. This Supplement presents the results of such an analysis. Since the analysis is theoretical, the derived solutions, naturally, do not fit exactly any one realistic situation. This does not, however, diminish the value of this study. The solution derived here shows what an optimal system of terminals with respect to factors included in the theoretical model would be and how much a realistic solution, adjusted on the basis of items (iii) and (iv) above, deviates from such an optimal system.

#### A. The Model

In order to make a solution more tractable, the following simplifying assumptions have been made for the theoretical model:

- (i) Trip end density per unit of time within the study area is uniformly distributed.
- (ii) All movements within the study area are along a gridiron pattern of streets. Consequently, users can move between two points only along right angle paths.
- (iii) Users select the terminals which are closest in distance to their trip origin and destination.
- (iv) There are no physical restrictions to any location of terminals.

It is reemphasized that, since actual conditions encountered in practice deviate from these assumptions, the results obtained from this study will require modification to account for departures from the assumptions, particularly in regard to assumptions (i) and (iv).

## 1. Qualitative Definition of Problem

The general optimization problem defined above has been decomposed into two sequential problems. These problems, solved within the framework of the above assumptions, are:

Problem 1: Find the optimal geometric pattern of terminals which minimizes:

- (i) users average access distance
- (ii) users maximum access distance.

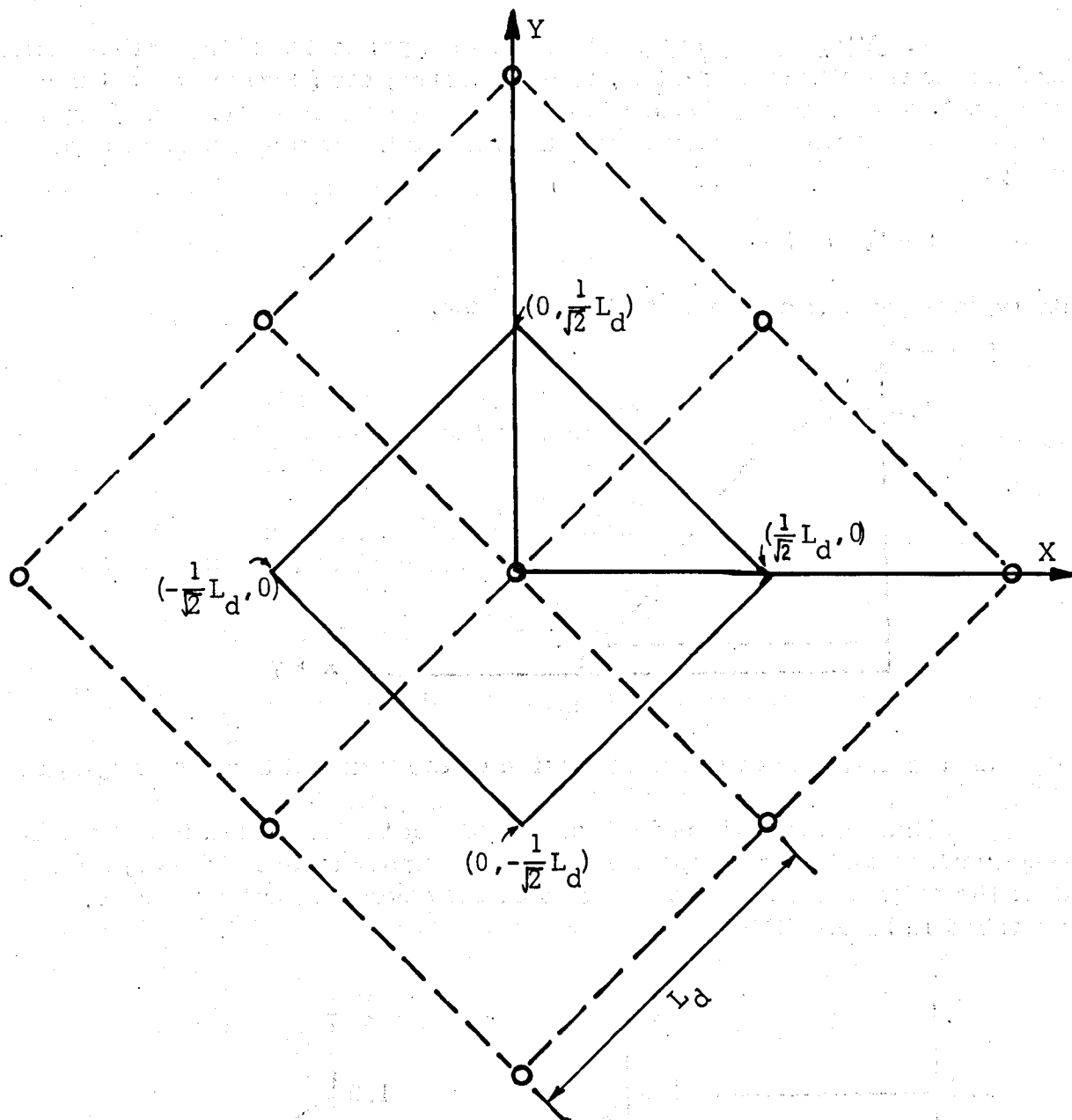
Problem 2: Find the optimal size and density (separation) of terminals within a given area for the pattern determined in Problem 1 which:

- (i) maximizes total number of users
- (ii) minimizes total terminal costs
- (iii) minimizes users maximum access distance
- (iv) minimizes users average access distance , and
- (v) minimizes ratio of number of users per terminal to number of parking stalls per terminal, expressing the degree of user convenience or probability of finding a vehicle in a terminal.

Most of these criteria partly overlap each other and affect both users and System operator. For example, the distance criteria are of direct importance to both parties: the more convenient the System is to use (in terms of distance), the greater will be the number of users. Similarly, the greater the number of users, the greater the operator's likelihood of building more terminals which consequently increases user convenience. Yet, each criterion must be examined individually and then introduced into the overall objective with a relative weight.

Numerous factors in addition to the five basic criteria presented herein were considered in the study, none of which were found to be of sufficient importance or substantially different from the five basic parameters to justify their inclusion in the fundamental problem formulation.

Problem 1 was solved during initial phases of research. A detailed discussion of the solution, presented in [ R - 5], indicates that the optimal geometry of terminal locations is the diamond pattern shown in Figure SIII-1. Using this pattern and the previously stated assumptions, the remainder of this section is devoted to the solution of Problem 2.



○ = Terminal Locations

— = Boundary of Terminal Service Area

$L_d$  = Spacing Between Two Nearest Adjacent Terminals

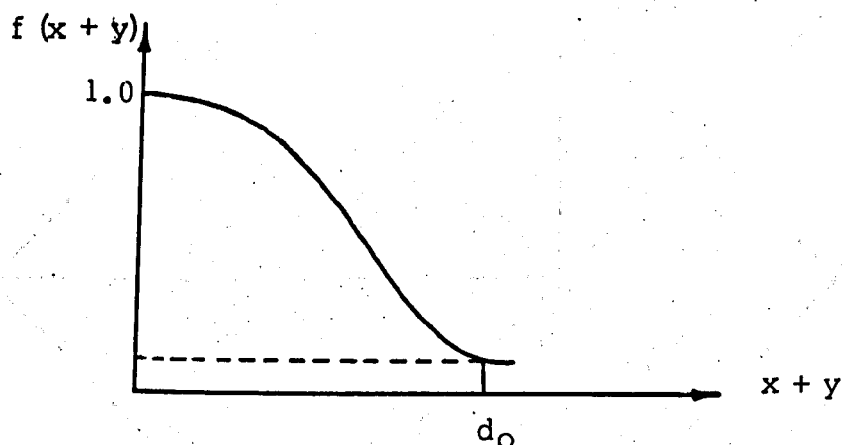
FIGURE SIII-1 OPTIMAL TERMINAL GEOMETRY

## 2. Mathematical Formulation of Optimization Problem

a. Attraction Factor. The important parameter of the optimization problem is the attraction factor,  $f$ , representing the fraction of total trips attracted to the Minicar System in a terminal's service area. This factor,  $f$ , is a non-increasing function of the distance to the terminal along the grid,  $x + y$ :

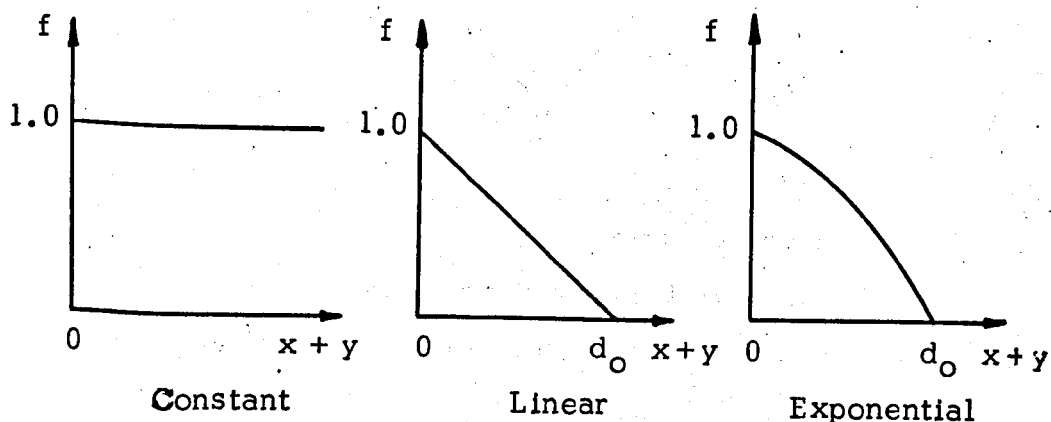
$$f = f(x + y) . \quad (1)$$

Its typical geometric form is sketched below.



$d_0$  is the distance at which attraction of the terminal becomes negligible.

The determination of the exact form of the attraction factor requires observations and data for the particular area under study. Lacking specific data the optimization analysis was made for several functional forms, sketched in Figure SIII-2.



FIGURESIII-2. ATTRACTION FACTORS

For the constant attraction factor, it is assumed that  $d_0 \gg L$ . Then

$$f = f(x + y) = 1. \quad (2)$$

This functional form is appropriate when competing forms of transportation are so inferior or costly as compared to the MTS that walking distance, within reasonable limits is unimportant.

In the case of a linear approximation

$$f(x + y) = 1 - \frac{x + y}{d_0}, \quad (3)$$

and two cases must be considered: (1) terminal service areas are contiguous, and  $L \leq \sqrt{2} d_0$ ; and (2) terminal service areas are isolated from each other and  $L > \sqrt{2} d_0$  (in this case  $f(x + y) = 0$ ).

In most instances the most realistic approximation to the attraction factor is an exponential function

$$f(x + y) = 2 - \exp \frac{\ln 2(x + y)}{d_0}. \quad (4)$$

As with the linear form, it is necessary to evaluate the two cases:  $L \leq \sqrt{2} d_0$ , and  $L > \sqrt{2} d_0$ .

b. Performance Index. The goals of the terminal system may be expressed in a quantitative measure of performance. If  $L$  is the shortest distance between two adjacent terminals (see Figure SIII-1), and  $S$  is the number of stalls/terminal (assumed to be the same for all terminals in a given zone), the performance index  $I(L, S)$  is defined as

$$I(L, S) = \frac{a_1}{U(L)} + a_2 C(L, S) + a_3 D_m(L) + a_4 D_A(L) + a_5 R(L, S), \quad (5)$$

where:

$U(L)$  is total number of users per unit of time in the zone of Area  $A_z$ .

$C(L, S)$  is total terminal cost (including investment and operating cost) for a given zone in dollars per unit of time.

$D_m(L)$  is users' maximum access distance in feet.

$D_A(L)$  is users' average access distance in feet.

$R(L, S)$  is number of users/unit of time/stall for a given terminal.

The coefficients  $a_1, \dots, a_5$  are called "leveling factors." They are needed to bring the values of the individual criteria to a dimensionally equivalent level and to introduce relative weights of individual factors. Since the relative importance of the individual criteria is subjective, values of these factors will vary depending on the particular case. The performance index must then be minimized for any set of values of these factors. This results in a sequence of minimized indices of performance with a different optimal separation and size of terminals in each case.

For a zone with area  $A_z$  the variables defined above are given more specifically as follows:

$$U(L) = \frac{4\gamma A_z}{L^2} \int_0^{L/\sqrt{2}} \int_0^{L/\sqrt{2}-y} f(x+y) dx dy, \quad (6)$$

where  $\gamma$  is the demand density.

$$C(L, S) = \frac{A_z}{L^2} (c_m + S c_t), \quad (7)$$

where:

$c_m$  is the fixed cost per terminal regardless of size and  $c_t$  is the additional cost for each parking stall, both in \$/unit time. Further,

$$D_m(L) = \frac{L}{\sqrt{2}}, \quad (8)$$

$$D_A(L) = \frac{\int_0^{L/\sqrt{2}} \int_0^{L/\sqrt{2}-y} (x+y) f(x+y) dx dy}{\int_0^{L/\sqrt{2}} \int_0^{L/\sqrt{2}-y} f(x+y) dx dy} \quad (9)$$

It is noteworthy that equations (7) and (8) are independent of the attraction factor. Further,

$$R(L, S) = \frac{4\gamma}{S} \int_0^{L/\sqrt{2}} \int_0^{L/\sqrt{2}-y} f(x+y) dx dy \quad (10)$$

Equations (6), (8) and (9) were derived in [R-5] for the geometric pattern of Figure SIII-1. Using these expressions, the performance index is completely defined.

c. Optimization Techniques. The optimal terminal system is the one for which values of L and S minimize the performance index function,  $I(L, S)$ .

Classical optimization [B-10] is utilized to find the minimum value. Using the necessary and sufficient conditions of calculus for a minimum, the first partial derivatives with respect to L and S of the performance index, equation (5), are set equal to zero, and solved for L and S (equations 11 and 12). The second order partial derivatives are found and their values checked to validate a minimum part, (equation 13). The conditions are represented analytically as:

(i) Necessary conditions

$$\frac{\partial I(L, S)}{\partial L} = 0. \quad (11)$$

$$\frac{\partial I(L, S)}{\partial S} = 0. \quad (12)$$

(ii) Sufficient condition

$$\left[ \frac{\partial^2 I(L, S)}{\partial L^2} \right] \left[ \frac{\partial^2 I(L, S)}{\partial S^2} \right] - \left[ \frac{\partial^2 I(L, S)}{\partial L \partial S} \right]^2 \geq 0. \quad (13)$$

The necessary conditions yield two equations with two unknowns, L and S. The values of L and S which are solutions of these equations will be at an extreme point of the performance index: a maximum, a minimum, or a point of inflection [B-10]. The sufficient condition is used to determine what solutions of the necessary conditions are true minimum points. Further, the solutions are only valid for interior points and not for boundary points.



## B. Solution of Optimization Problem

### 1. Constant Attraction Factor

For  $f = 1$ ,

$$L = \left( \frac{2 a_2 c_m A_3}{a_3/\sqrt{2} + \sqrt{2} a_4/3} \right)^{\frac{1}{3}}, \quad (14)$$

and

$$S = \left( \frac{a_5 \gamma}{c_t} \right)^{\frac{1}{2}} \left( \frac{2 c_m}{a_3/\sqrt{2} + \sqrt{2} a_4/3} \right)^{\frac{2}{3}} (a_2 A_3)^{\frac{1}{6}}. \quad (15)$$

The equation for sufficient condition is:

$$3 a_5 (c_m + S c_t) A_3 \gamma L^4 - 2 a_5 c_t A_3 \gamma L^4 S - a_2 (c_t A_3 S)^2 \geq 0. \quad (16)$$

The values of  $S$  and  $L$  defined by equations (14) and (15), respectively, must satisfy equation (16) in order to make a true minimum.

### 2. Linear Attraction Factor

Case 1:  $L \leq \sqrt{2} d_0$ . Partial differentiation of the performance index results in:

$$S = \left( \frac{a_5 \gamma [1.5 d_0 - L]}{a_2 c_t A_3 [1.5 \sqrt{2}]} \right)^{\frac{1}{2}} L^2 \quad \text{and} \quad (17)$$

$$\begin{aligned} & \frac{a_1 1.5 \sqrt{2} d_0}{A_3 (1.5 \sqrt{2} d_0 - L)^2 \gamma} - \frac{2 a_2 c_m A_3}{L^3} + \frac{a_3}{\sqrt{2}} + \\ & \frac{a_4 (1.5 \sqrt{2} d_0 - L) (8 d_0 - 6 \sqrt{2} L) + (8 d_0 - 3 \sqrt{2} L) L}{8 (1.5 \sqrt{2} d_0 - L)^2} - \\ & \left( \frac{a_2 a_5 \gamma c_t A_3}{1.5 \sqrt{2} d_0 (1.5 \sqrt{2} d_0 - L)} \right)^{\frac{1}{2}} = 0. \end{aligned} \quad (18)$$

Consequently  $L$  can be determined from equation (18) and then  $S$  can be obtained from equation (17).

Case 2:  $L > \sqrt{2} d_0$ . Substituting equations (6) through (10) into (5) and solving for  $S$  yields:

$$S = \left( \frac{2 a_5 \gamma}{3 a_2 c_t A_3} \right)^{\frac{1}{2}} L d_0. \quad (19)$$

$$\frac{3 a_1 L^4}{8 A_3 d_0^2} + \frac{a_2 L^3}{\sqrt{2}} - 2 a_2 \left[ c_m + \left( \frac{2 a_5 \gamma c_t}{a_2 A_3} \right)^{\frac{1}{2}} L d_0 \right] = 0. \quad (20)$$

The sufficient condition for optimality was not developed in analytical form, but was determined by a search procedure to obtain the true minima in each case.

### 3. Exponential Attraction Factor

Case 1:  $L \leq \sqrt{2} d_0$ . Substituting equations (6) through (10) into equation (5) gives in this case the following index of performance  $I(L, S)$ :

$$I(L, S) = \frac{a_1}{U(L)} + \frac{a_2 A_3}{L^2} (c_m + S c_t) + \frac{a_3 L}{\sqrt{2}} + \frac{4 a_4 \gamma A_3 X(L)}{U(L) L^2} + \frac{a_5 L^2 U(L)}{A_3 S}. \quad (21)$$

Taking the partial derivatives of (21) with respect to  $L$  gives

$$\begin{aligned} & \frac{4 a_4 \gamma A_3 \frac{\partial}{\partial L} \left( \frac{X(L)}{L^2} \right)}{U(L)} - \frac{a_1 L^2 + 4 a_4 \gamma A_3 X(L)}{(U(L) L)^2} \frac{\partial}{\partial L} U(L) - \\ & \frac{2 a_2 A_3 (c_m + S c_t)}{L^3} + \frac{a_3}{\sqrt{2}} + \\ & \frac{a_5 L (2 U(L) + L \frac{\partial}{\partial L} U(L))}{A_3 S} = 0. \end{aligned} \quad (22)$$

$$S = \frac{L^2 a_5 U(L)}{A_3 a_2 c_t} \quad (23)$$

By simultaneously searching for solutions to equations (22) and (23) the optimal values of S and L may be obtained.

Case 2:  $L > \sqrt{2} d_0$ . Again, partial derivatives of  $I(L, S)$  are taken, leading to:

$$\frac{2a_1 L}{4\gamma A_3} \cdot \frac{1}{d_0^2 - \frac{2d_0^2}{\ln 2} + \left(\frac{d_0}{\ln 2}\right)^2} - \frac{2a_2 A_3}{L^3} (c_m + S c_t) + \frac{a_3}{\sqrt{2}} = 0 \quad (24)$$

and

$$S = 2L d_0 \left\{ \frac{a_5 \gamma \left[ 1 + \frac{2}{\ln 2} + \left(\frac{1}{\ln 2}\right)^2 \right]}{a_2 c_t} \right\}^{\frac{1}{2}} \quad (25)$$

Optimal values of L and S can be determined by the simultaneous solution of equations (24) and (25). The sufficient condition for optimality was not analytically developed for either case, but was determined by a search procedure to find the true minima.

The analytical expressions for optimal terminal locations and size derived here were used for development of a computer program capable of computing the optimal values of the variables S and L for any given conditions and set of relative weights of individual criteria. Specific values for  $A_3$ ,  $\gamma$  and  $d_0$  were taken for an actual zone in Philadelphia CBD. The terminal costs as well as the leveling factors were given hypothetical values. Optimal values of L and S were obtained for different sets of parameter assumptions.

Evaluation of the results showed that more time was necessary in analyzing trade-offs between parameter assumptions and output prior to establishing a specific optimal terminal system for the area. Accordingly, the details of the example are not included in this Report.

## C. Conclusions

### 1. Technique of Optimization

The technique used to solve the optimization problem is presented in a form which allows derivation of the optimal solution for any set of relative values of individual criteria. Thus the designer has a capability of changing the relative values of the criteria for different areas or within the same area and estimating the trade-offs between them.

However, although the technique used is based on relatively simple mathematical relationships, the additional factors which must be taken into account in actual planning of terminals, can make subsequent implementation quite complex even for a relatively simple attraction factor.

## 2. Possible Future Research

The techniques presented here are conducive to extensions in several directions, some of which are briefly summarized below.

A sensitivity study can be performed by a method of max-ranking criteria. The basic purpose of this procedure is to rate each system attribute against an absolute scale of desirability.

Analysis of random demand for Minicars through application of queueing theory (which applied to telephone systems, air traffic and many other fields of transportation) could be used in the determination of optimal size of terminals.

Dynamic optimization of terminals is another possible extension. Since all terminals would not be introduced at once, but their density in an area would gradually increase, it is desirable to derive the optimal sets of terminals for different stages of their introduction, i.e. with varying system size constraints.

Investigation of demand functions, varying with distance and time, would lead to further realistic value of the model. Other attraction factors could also be developed if an appropriate mathematical programming procedure is found.

## Technical Supplement S-IV

### INFORMATION SYSTEM

#### A. Introduction

Efficient operation of the MTS requires an automated information management system for controlling check-in/check-out transactions of cars and for supporting maintenance, service, control of terminals and other operational activities as well as for generating pertinent data for accounting, billing, statistical and management purposes.

Preliminary studies of the need for and the possible nature of the Information System (IS) were underway since the inception of the MTS project. These preliminary investigations, carried out by the Management Science Center, are summarized in reference [T-9]. That report considers in detail many of the functional requirements that the ultimate Information System must satisfy. The synthesis of the design of the actual system, however, was not affected as the detailed functional requirements are very dependent on the design of the total MTS. Evolution in the design of the MTS has been sufficient to change many of the initial assumptions made in early IS studies; for that reason the findings of these early studies are not repeated here.

In May 1969 studies of the IS were continued under the direction of Dr. Schrenk. Preceding work by the Management Science Center was studied in depth and a new approach to the IS was developed. Creative engineering work effected the synthesis of a realistic and highly modular IS design which can meet the requirements of the MTS concept both as it is today and as it is likely to evolve. During the course of this creative engineering work numerous concepts were considered and effects of a number of variations of the total MTS concept were explored. It was considered most important that an actual preliminary modular design be developed, which would then serve as a basis for specific detailed discussions with other research teams on the Minicar Project. It was expected that this preliminary design would assist in finalizing the MTS concept and then in finalizing the design objectives and functions of the IS. The synthesized preliminary design is described in the sections that follow. The IS design objectives and functions were not finalized by the time of the Project termination.

In addition to work described herein, and in conjunction with preliminary terminal design efforts considerable work was done by Minicars, Inc. on the design of Minicard readers and wayside terminals. Early considerations on alternate designs for automatic billing-coding devices and schemes for vehicle and customer flow in response to "noisy" demand functions were reported in [T-6c].

Subsequent work by Minicars, Inc. resulted in the design, fabrication and preliminary evaluation of an MTS car data unit and wayside terminal. The car-mounted electronics weighed ten pounds, occupied 0.1 cubic foot, and was shown to produce the necessary signals with sufficient quality for telephone line transmission. The charge information transmitted included 14 serial characters coded in touch tones. An inductive link was used for transmission of data from the car to the wayside terminal and was shown to have a pattern with excellent angular selectivity and high tolerance to car position. Details of the design, fabrication and preliminary evaluation of this unit are reported in [T-6e].

#### B. Preliminary Design Considerations

The major design objectives for the IS are:

1. Modular system which can be implemented with use of currently existing technology and presently available or easily engineered components and which can easily utilize future technological developments.
2. Fully automated operational control with dynamic display of important operational parameters.
3. Automated financial control and accounting procedures.
4. Maximum customer convenience.
5. High reliability.
6. Reasonable capital cost and low operational cost per transaction.
7. Provision of back-up systems where necessary.
8. Compatibility with other elements of the MTS.

A preliminary description of the functional requirements of the IS follows:

1. Customer validation - is the Minicard valid? What is the expiration date?

2. Vehicle validation - does the vehicle need service? Is the vehicle being held for an inquiry?
3. Automatic gate release - if customer and vehicle validation are O.K. and pertinent data have been received.
4. Processing of exceptions - if customer or vehicle does not check, an operator is alerted to talk to the customer - the customer will be appropriately directed.
5. Completion of transaction when vehicle is checked in.
6. Response to inquiries by customers, public agencies, operating personnel.
7. Dynamic directions to operating personnel for maintenance and/or servicing or redistribution of vehicles among terminals.
8. Appropriate operating procedures during central system down time.
9. Status changes of customers, vehicles, or terminals.
10. Handling of cash transactions if MTS concept is ever modified to permit same.
11. Dynamic display of operational parameters.
12. Accounting and billing of customers.
13. Financial and statistical reports, operational analyses, predictive modeling, etc.

#### G. General Description of the Preliminary System Design

Based on a detailed study of current concept of the MTS and the design criteria described in the preceding section, the Information System shown in Figure SIV-1 has been synthesized. The schematic identifies two major parts of the IS - the Remote System and the Central System: the Remote System includes hardware for the terminal and vehicle, for data entry and transmission, and for communications links for exchange of data and control signals with the Central System; the Central System consists of a dedicated on-line command and control computer system and a conventional off-line computer system. The command and control system will provide the rapid response necessary for automated check-in/check-out procedures and will dynamically display the operational status of the MTS; this system will dynamically control all MTS operations and respond to a wide variety of possible inquiries. The off-line system will perform conventional accounting and billing functions, provide statistical and management reports, etc.

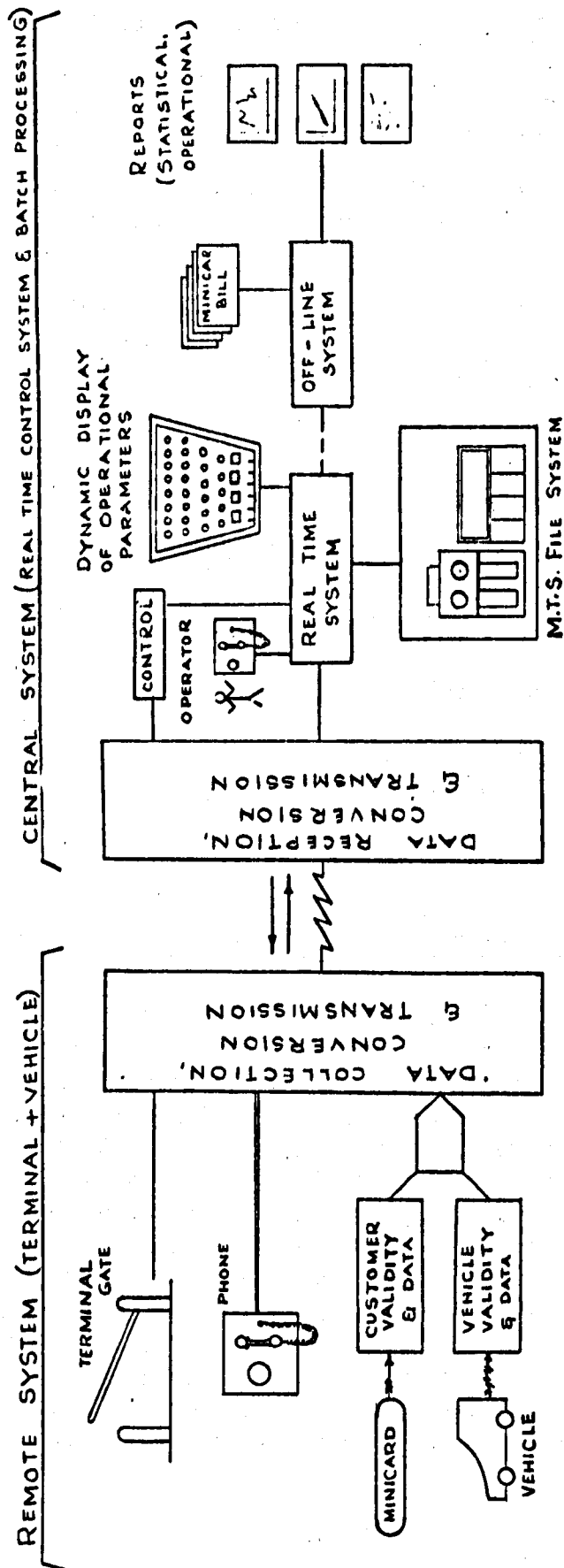


FIGURE SIV-1. DIAGRAMMATIC DESCRIPTION OF THE MINICAR INFORMATION SYSTEM



To understand the Information System design, let us consider the operation of the system in a typical transaction. The customer enters a Minicar terminal, gets into the first available vehicle and drives to the exit gate. He stops before the gate, reaches outside the vehicle and inserts his Minicard into a card reader in the Remote System terminal check-out standing alongside his car. Insertion of the Minicard activates data entry devices and the information on his card and the information from the car, via appropriate data communication links, are transmitted to the Central System; the central command and control computer system checks if the customer's account is valid, checks if the vehicle may be checked out, then resets distance and elapsed time counters in the vehicle and indicates by a special signal to the customer that the transaction for check-out is complete. The customer removes his Minicard, the exit barrier is released automatically, and he drives out. For the check-in portion of the transaction, a similar operation is performed and the customer, after driving and parking the vehicle inside the terminal, leaves. If any part of the transaction does not proceed smoothly, an operator at the Central System is alerted and the customer talks direct to the operator using a car-side telephone. Should the customer encounter any problems or have any questions, he may use the same telephone to talk directly to the operator.

The above discussion is summarized in the functional diagrams of the IS shown in Figure SIV-2. The two major parts of the IS - the Remote System and the Central System - will now be discussed in detail.

a. Remote System. The functional diagram of Figure SIV-2 indicates that the Remote System can be divided into the following subsystems:

- (1) Vehicle data generation devices
- (2) Data transmission link between vehicle and terminal
- (3) Customer data collection devices
- (4) Auxiliary devices to perform such functions as providing a printed receipt, allowing use of cash transactions, direct voice line to central facility, etc.
- (5) Data transmission line between terminal and central facility.

In order to define completely a transaction and to ascertain the validity of the request for service, the following data items are required:

- (1) Customer account number
- (2) Account expiration data
- (3) Type of service (flat rate, trip rate, etc.)

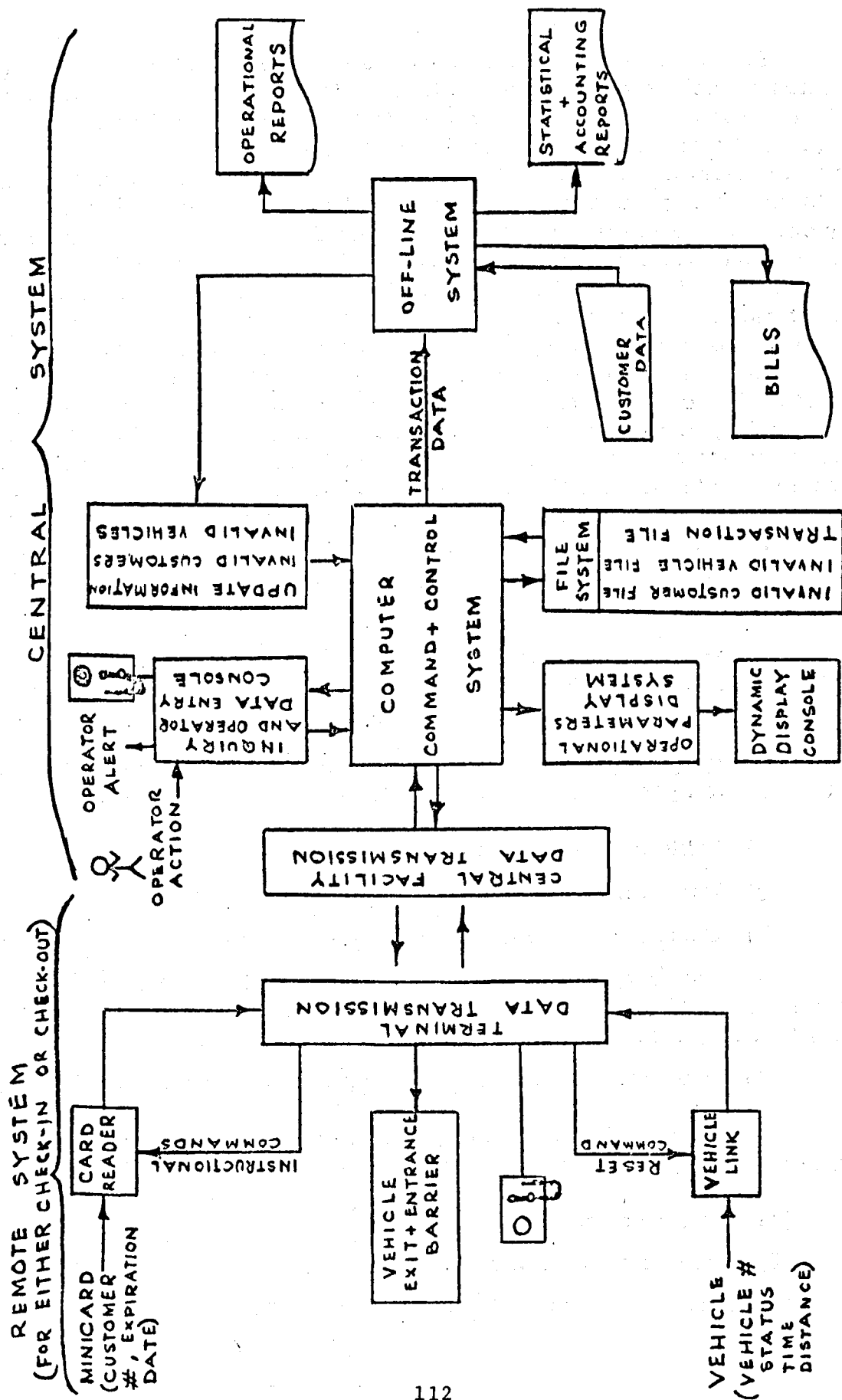


FIGURE SIV-2. FUNCTIONAL DIAGRAM OF THE MINICAR INFORMATION SYSTEM

- (4) Type of transaction (credit or cash)
- (5) Terminal identification
- (6) Date and time of transaction
- (7) Vehicle identification number
- (8) Vehicle operational status (usable or requiring service)
- (9) Mileage used during rental
- (10) Elapsed time of rental.

The first four data items can best be obtained from the Minicard. Items 5 and 6 are best generated at the Central System. Items 7 through 10 must be procured by data generation devices on the vehicle and automatically transmitted to the terminal during check-in/check-out by an appropriately designed car-to-terminal data transmission device.

The Minicard cannot be considered without considering the associated card reader. Card readers presently under study utilize one or more of the following means of data storage:

- (1) Optical
- (2) Magnetic
- (3) Punched hole
- (4) Phonograph grooves.

The card reader should also be capable of retaining the card being read and removing same from circulation upon an appropriate signal from the central facility. This "destruct" feature, however, must not make the card reader require human attention before accepting another card for processing. Further study is required to select the best system for this case. Basically, however, card readers that are sufficiently sensitive to be able to detect most types of fraudulent cards are fairly expensive and rather delicate devices; consequently, in order to obtain high enough reliability at reasonable cost, our proposed design shows the card reader alongside each exit/entrance terminal gate. Further investigations should determine if the card reader should be located inside the vehicle, as was initially proposed.

Four types of vehicle data generation devices have been delineated as necessary (items 7 - 10). The elapsed mileage indicator (item 9) and elapsed time indicator (item 10) should probably be electromechanical devices with associated digital readouts that are automatically reset at check-out time. Further study is required to select the actual devices to be used.

During check-in/check-out, vehicle data must be automatically transmitted over an appropriate two-way data communication link to the car-side terminal device. The following methods are presently available for this transmission:

- (1) Radio frequency
- (2) Induction coil (magnetic)
- (3) Optical
- (4) Electrical contact
- (5) Ultrasonic.

The mode to be selected can depend very heavily upon the physical design of the terminal facility. In fact, it may prove to be very desirable to equip each vehicle with two modes of transmission - a primary mode and a backup secondary mode (such as a plug from the car-side terminal to the vehicle) for use in event of failure. The selection of the appropriate mode or modes may require extensive vehicle/terminal design mock-up studies.

In order to satisfy the design requirements of the system, leased telephone lines should be used from the central facility to the remote terminal. In Philadelphia, for example, leased lines are less costly than message unit dial-up facilities. With leased lines, response time will be shorter, data transmission accuracy will be better, and custom engineered data sets can be employed to handle the special data communication needs of the MTS Information System.

Provisions have been made in the modular design of the Remote System that will easily permit the Information System to handle cash transactions. Cash transactions may be particularly desirable in order to allow persons who are questionable credit risks to use the MTS. Further study into various types of change-making equipment is required in order to ascertain that cash transaction modules can easily be added at any time.

b. Central System. The Central System, also shown in Figure SIV-2, is composed of the following major components:

- (1) Data Communication System
- (2) Hardware for the on-line command and control computer system
- (3) Software for the on-line command and control computer system
- (4) Operational Parameters Dynamic Display System
- (5) Hardware/Software for off-line computer processing system.

The insertion of a Minicard in a reader at the Remote System terminal check-out device will activate the transmission of vehicle and customer data to the central dedicated on-line command and control computer system. This command and control system will examine the data and check the customer and vehicle files to see that the customer account and vehicle number are not invalid. If all tests are satisfied, the system will enter a transaction record and issue a signal that causes the Remote System to reset vehicle elapsed time and mileage counter and to release the Minicard and the exit gate (upon removal of the Minicard from the card reader).

Should the command and control system find the transaction unacceptable for any reason, the processing of the transaction is automatically transferred to a human operator for resolution and the user at the terminal is signaled to pick up the car-side phone. The human operator can do whatever he deems necessary to resolve the problem. Should he ascertain that the card being used is invalid, he can signal the remote terminal card reader to "destruct" the card.

Should the user at a remote terminal wish to talk with a human operator at any time, the user can pick up the car-side phone and will automatically be connected to a human operator at the Central System.

The above description is for check-out; similar procedures will be used for check-in.

During check-in a transaction file will be updated so that the off-line system can subsequently do the billing and accounting function. The command and control system will generate all data necessary for the billing of credit customers, vehicle usage, total MTS use, etc. Processing of these data will be done by an off-line computer system. Software available for usual business data processing tasks, such as accounting, statistical and management reports, etc., may be used as a basic package from which to generate an MTS off-line computer system. Further study is required to ascertain whether the off-line computer hardware should be leased or purchased for use solely by the MTS or whether the processing time needed should be purchased from other commercial data processing firms.

The central on-line command and control computer system will also contain an inquiry and operator data entry console which the operator can use to query the system or enter information into the system. The delineation of the exact features of this inquiry and operator data entry system requires further study.

The central on-line command and control computer system will also contain an operational parameter dynamic display system. This system must dynamically display critical operational parameters such as:

- (1) Maintenance, service or repair needs by type and terminal location .
- (2) Number of available operational vehicles by terminal location.
- (3) Problems necessitating immediate human attention.

Operational information will be presented by means of a visual electronic board dynamically displaying, by terminal, the MTS operational status. Included in this system will be the ability by means of control switches to override the automatic operation of various critical items of terminal equipment.

The design of the file system for the on-line command and control computer system is a critical problem area. The following files must be present:

- (1) Invalid Customers
- (2) Invalid Vehicles
- (3) Pending Transactions
- (4) Operational Status
- (5) Completed Transactions.

The first 4 files must be random access; the fifth file might be a sequential tape file as it is the file that is passed to the off-line computer system. A detailed specification of the file structure must await the finalization of many other aspects of the system.

An integral part of the design of the Central System must be the inclusion of provisions for handling and recovering from all types of system failures. Problems with a Remote Terminal will present inconvenience to only those customers trying to use the particular terminal. Any malfunction in the Central System, however, affects all elements of the Remote System and all users. Therefore, it is necessary that the design of the Central System not only be modular, but also very reliable. These provisions for handling and recovering from all types of Central System failures may be backup components in some cases or they may even be a complete duplicate backup system. Basic design consideration for these provisions is that the user must never be aware of Central System failures. Backup systems and/or backup procedures have not been studied in detail.

Implementation of the Central System will depend on the way the total MTS is put in operation. If a phased implementation is used for the MTS, then a phased initial implementation of the Central System can also be used. From the very beginning it is absolutely necessary to have a Central Facility which will be the "management brain" of the operation and have all data from all terminals available.

The Central Facility, however, can initially be operated by persons who will manually make validity checks of customers and vehicles and release by remote control the vehicle gates at the terminals. The recording of the necessary trip data to be used for billing and accounting purposes can be easily automated through the use of various types of data recorders. The operator at the Central Facility will have complete remote control of all terminal equipment. Operational parameters for service, maintenance and other operational problems can be generated manually.

When the number of vehicles and customers approaches the limit of efficient response by the operators, the on-line command and control computer system will be introduced along with other hardware and software necessary to automate all operations. Only problems or questions would then alert the human operator; normal transactions would be automatically processed by the on-line system. Automation of the determination and the dynamic display of operational parameters would be implemented at the time the on-line computer is introduced. Proper design of the system would allow the hardware that was used for the original manual system to be used for handling problems and questions in the fully automated system.

## Technical Supplement S-V

### MTS OPERATIONAL FEATURES

#### A. Interterminal Operations

Regular operations of Minicars in the streets are not expected to cause serious problems. Users would drive the Minicars from one terminal to another, parking at different intermediate points in the same way as other automobile drivers do. In the case of a vehicle breakdown, accident or other emergencies, the user could call the MTS office and an emergency vehicle would be sent by the System to the site.

A major problem of interterminal operations, however, is redistribution of vehicles. It is very likely that the demand for Minicars will not be spatially balanced in the short run, as well as on a 24-hour or weekly basis. For example, it appears likely that persons coming by transit into the city will walk to a shopping area, while after shopping, having several packages, will rent a Minicar to take them to the nearest transit station. Some commuters are more likely to use Minicars between transit stations and their places of business in going to work than in their return home after work. In addition, such events as a storm may also cause such "unsymmetric" utilization of Minicars. This travel pattern will then create the problem of how to return the extra vehicles from the locations with a surplus of Minicars to the locations which have a deficiency of vehicles. Various aspects of this problem have been studied and the findings are summarized here.

The data on personal travel within urban areas available to this study were not detailed enough for a complete projection of exact origins and destinations of individual trips and their temporal distributions. While it would be possible to make a stochastic model of vehicle movements as a function of certain assumed demand patterns, the input into that model would be so hypothetical that its results would have an unknown and probably very low validity.

In addition to estimation of volume of redistribution which would be required, analytical methods will be needed for operating decisions to optimize fleet utilization. Some aspects of this problem have been analyzed in papers [ T-8, a, b and c ].

The problem of estimating the total volume of Minicar redistribution has been the underlying difficulty in developing specific recommendations for this operation. The possible vehicle redistribution methods are listed here with their positive and negative aspects.



One method of redistribution is to ship the Minicars between terminals by large semi-trailer trucks in the same way as new automobiles are shipped. Each semi-trailer would, of course, carry a considerably greater number of Minicars than standard automobiles due to their shorter length. This method of redistribution would be economical, but it would create problems in the narrow streets of central urban areas. The trucks would be highly objectionable during the daily hours because of their contribution to congestion. At many points in the central urban areas they would have difficulties in negotiating tight intersections.

Minicars are designed to be easily coupled in short trains so that one driver can take several vehicles from one terminal to another. Driving of rubber-tired vehicles in trains presents problems of stability and this limits the speed or length of the trains. Exact estimates of the maximum feasible speed/length combination are difficult to make before trains of vehicles are actually tested, but it appears that it would be possible to run trains of four Minicars at a speed of 10-15 mph through city streets. This method would be operationally very simple, but it would require considerable labor.

Redistribution by both of these methods could be performed most efficiently during the night hours by employees who are also assigned other operational or maintenance tasks not requiring a full eight hours.

The volume of Minicar redistribution can be reduced by two different methods. First, there is a trade-off between the fleet size and number of vehicles which have to be redistributed. If the fleet is larger, redistributions have to be performed less frequently and in larger numbers at once. Thus with larger fleets it would be practical to utilize semi-trailer trucks during night hours. Naturally, increasing fleet size for this purpose would represent a trade-off of investment in fleet vs. saving in labor for redistribution. A second method of reducing redistribution volume is the introduction of market incentives once the travel patterns of Minicar users are established. For example, rates could be lowered for trips which would result in better redistribution of Minicars. Thus, an inducement would be given to the public to make such use of the System as minimizes required redistribution. While this method would present some complication in accounting and providing information to the public, it might prove to be an economical and logical way, following the pattern which is often utilized in the marketing of various products as well as in some transportation services.

#### B. Intraterminal Operations

Upon entering a Minicar terminal, potential customers would be directed to the vehicles which are ready for use. They select a vehicle, start it and drive it to the check-out gate. There the information system checks the vali-

dity of a user's Minicard as well as the mileage and number of the vehicle he is using. If the check is satisfactory, the barrier opens and the customer leaves the terminal. In the case where the information system rejects the user for some reason the customer can then use the telephone service to check the reason for rejection. The design of the terminal provides for return of vehicles containing rejected users to the Minicar storage area.

When the user arrives at a terminal with a Minicar, the information system at the check-in gate reads his card, mileage on the vehicle and the time. The barrier is then opened and the driver takes the vehicle either into the parking area, or if there is an indication of malfunction or the light on the Minicar panel indicates need for refueling, or if the computer signals the need for routine maintenance, the user is directed to take the vehicle to the maintenance area.

Conceptually, it appears possible that all these operations could be fully automated. The most serious problems of automation are customers who need help, additional information or security. Some surveillance is therefore always needed. There are two ways in which this surveillance could be provided without assigning an MTS attendant to each terminal exclusively. The first arrangement is to utilize attendants at existing parking garages from which a portion has been taken and converted into a Minicar terminal. This is entirely feasible, although the details of such arrangements have not been studied. Another way of providing security is to install television cameras so that surveillance by one person can be performed from one central location for ten, twenty or even more terminals, depending on the level of activity in them. The effectiveness of this system cannot be ascertained until tests are made, since it greatly depends on the attitude of the public toward the system, on the population of the area, police surveillance of the neighborhoods, etc. While problems of vandalism in many urban areas make this solution rather unrealistic, the experience with stations of the new rapid transit line between Philadelphia and Lindenwold, New Jersey, which are completely automated and supervised by one to two persons from a central location, has been highly satisfactory.

The method of terminal surveillance may justifiably vary from one system to another and from one area to another. It is, therefore, desirable to study this problem for specific areas before a system is introduced. Detailed analysis is essential since security is critical to demand and automation is critical to economic feasibility.

### C. Terminal Layout

The purpose of research in this area was to set up criteria and guidelines for the functional design of MTS terminals. Since detailed design of each terminal would have to be developed individually, it was decided to develop service modules (eg. check-in and check-out gates, maintenance area, aisles, etc.) which would satisfy the requirements of users, MTS operator and city (or "environment"). Different modules can be combined for different terminals. One typical terminal layout is shown in Figure SV-1.

Although an appreciable amount of research was done in this area, it has not been completed and its results are therefore not included in this Report.

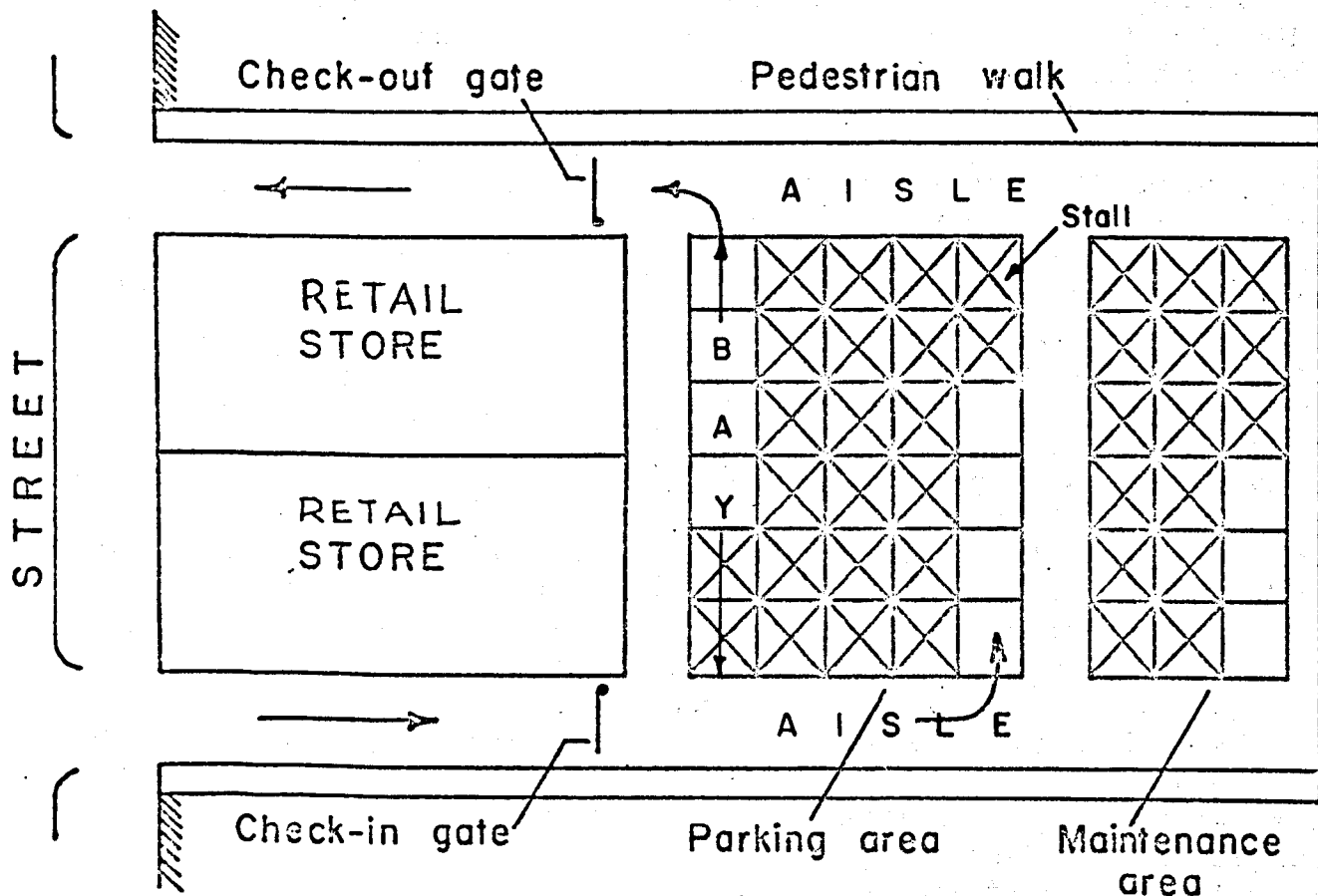


Figure SV-1. TYPICAL TERMINAL LAYOUT

#### D. Terminal Design

Local design codes for conventional parking garages will in most cases control the design of either new or renovated parking structures for Mini-cars. Certain operational aspects of the MTS, such as user access to vehicle storage areas and the performance of service and maintenance of vehicles within the structure, will require additional features not usually included in parking garages. These include high intensity lighting, special drainage facilities, good pedestrian facilities and architectural treatment.

The Phase I research was not extended during Phase II and detailed terminal design should be the subject of future research.

#### E. Maintenance

##### 1. Objectives

Successful operation of the MTS requires such vehicle and facilities design that maintenance cost can be minimized and an effective system of inspection and servicing provided.

Maintenance considerations apply to all physical elements of MTS including:

- Personal vehicles
- Service, emergency, and all other MTS vehicles
- Terminal buildings, facilities and equipment
- Maintenance buildings, facilities and equipment
- Administration buildings, facilities and equipment
- Communications equipment.

The phases of maintenance given particular attention within this study were the following:

- (i) Maintenance features in vehicles and terminal design;
- (ii) Conception of maintenance systems for the Minicar vehicles;
- (iii) Consideration of maintenance costs within the economic analysis;

Special emphasis has been devoted to integration of the Maintenance System with the other components of the System, particularly the vehicle and terminal systems.

## 2. Design Considerations

Two basic aspects of terminal design are efficient vehicle servicing within the terminal and easy maintenance of the terminal facility itself. Vehicle servicing within the terminal was a principal criterion in determining the size of the terminal, its configuration and intra-terminal operations.

All components of the vehicle are designed to eliminate major and unique maintenance problems, to minimize routine maintenance, to maximize vehicle life, to discourage vandalism, and to facilitate inspection and diagnosis. Wherever possible, utilization is made of high quality materials, simplicity in detail, standard production parts, modular replacement and rugged construction. Specific examples of such utilization in component design are the fiberglass body, peripheral rubber bumper, heavyweight vehicle frame, fixed seat structure, and power train unit. A more complete description of the vehicle components is found in Technical Supplement S-1.

## 3. Vehicle Servicing and Maintenance Requirements

For development of optimum vehicle servicing procedures the following maintenance principles were established:

- (i) All mechanical components must be in good condition for full safety protection of the driver and public;
- (ii) Mechanical and electrical failures must be minimized;
- (iii) Optimal performance and smoothness of operation and comfort must be maintained;
- (iv) Noise, odor and exhaust emission must be at minimum levels;
- (v) Vehicle cleanliness, inside and out, must be continuously preserved;
- (vi) Maintenance costs must be minimized and vehicle life maximized consistent with the previous standards.

Proper development of a maintenance program requires estimation of the number of vehicles within the System, their rate of usage, and the characteristics of the vehicle components. Studies for this Report assumed 8000 and 25,000 car systems with an average monthly usage of 1000 miles per vehicle. Component lifetimes are dependent upon numerous variables, with the type of individual use of the vehicle being one of the more difficult factors. Lifetime estimates were obtained utilizing many considerations from numerous sources including national production figures, personal vehicle design groups, experienced automotive maintenance personnel and factory recommended information. Comprehensive parts and subassembly lists were made, service functions were compiled, maintenance group assignments established, and a tentative service schedule developed. These data

are given in the Appendix to reference T-6b1 . In addition to determining the extent and frequency of maintenance functions it was also necessary to estimate the time required for specific repairs, and on these bases to develop equipment needed, location of servicing and the overall maintenance procedure.

For purposes of study as well as implementation, vehicle servicing and periodic maintenance have been subdivided into the categories of Inspection and Diagnosis, Routine Service, Minor Maintenance, Major Maintenance, Overhaul and Emergency Service as described below. It is realized that some overlapping of work among the several categories will occur.

a. Vehicle Inspection and Diagnosis - The inspection and diagnostic procedures used for the Minicar are the fundamental elements in fulfilling the vehicle's maintenance criteria. The diagnostic program is carried out through several levels ranging from simple visual inspection to computerized analysis. Inspection procedures are performed throughout all stages of the vehicles maintenance, from daily servicing to major overhauling.

Extensive study of current diagnostic systems and their applicability to the MTS was made and is reported in reference [T-6b]. Such systems as (i) vehicle diagnostic centers utilizing specialized electronic engine analyzers, dynamometers, etc. (ii) Mobile Automotive Test and Inspection Centers (MASTIC), a mobile unit developed and used by the Pacific Telephone Company; or (iii) portable automated systems under development for military use have potential applicability to the MTS. Specific recommendations for usage of equipment of this degree of sophistication and cost can be made only after further development of these systems, more detailed assessment of MTS requirements and complete comparisons are completed.

Maximum feasible utilization of automation and computer analysis is recommended for Minicar maintenance diagnosis. Applicability of a diagnosis computer system similar to the U.S. Army's M.A.I.D.S. system was analyzed for the MTS, as reported in [T-6a]. A local computer would be used to transfer instructions from a central computer to the operator as to which tests and procedures are necessary for a particular vehicle. Also generated would be diagnostic driving functions, data reduction and diagnostic and maintenance history. Transducers, mounted in the cars, and portable units, would be necessary to measure the response of the car to the programmed stimuli. Maintenance System Diagrams, Computer Flow Charts and Preliminary Diagnostic System Requirements Listings were developed. The cost savings and reliability improvements possible through such a computer system suggest further study to develop specific utilization recommendations to the Minicar maintenance program.

b. Routine Service includes cleaning the vehicle's interior and exterior, refueling and maintaining the required oil and water levels. It further includes adjustment or replacement of items such as windshield wipers and lamps which can be accomplished in 5 - 10 minutes, anywhere in the terminal, with a minimum of equipment, generally with hand tools.

Interior cleaning is recommended daily utilizing conventional vehicle vacuum cleaners. Utilization of a vacuum blower system with ports on the interior of the vehicle may prove feasible to reduce cleaning time and costs.

Exterior cleaning is recommended at intervals between four and seven days, depending on conditions. Special considerations are necessary for winter conditions in regard to frequency of cleaning and additional facilities for drying. Cleaning methods studied included (i) conventional high capacity production wash racks requiring movement of vehicles between terminals, (ii) small minimum quality wash racks in each terminal, (iii) a mobile rack traveling to terminals, (iv) a completely mobile system that washes cars without moving them. This last system presents problems in winter washing, water removal, and development time and costs. Specific recommendations depend upon the overall maintenance system used as discussed in the following section.

Frequency of refueling depends on gas mileage, vehicle usage and fuel tank capacity. It is estimated that the MTS vehicle will require refueling on an average of once per week, with approximately 20% of the vehicles needing fuel each weekday. Vehicles may be fueled in place by conventional mobile filling systems or high pressure systems; or moved to a fixed facility within the terminal or outside. Selection of system is dependent upon other maintenance procedures.

c. Minor Maintenance consists of such tasks as changing oil filters and batteries and performing tune-ups and brake adjustments. This work will normally occur at 3 to 6 month intervals and generally require less than one hour. Since in some cases specialized equipment will be required, minor maintenance may be done in either a central facility or within a special terminal service area.

d. Major Maintenance includes such jobs as wheel alignment, brake replacement and body repairs which require specialized equipment and take over an hour at a frequency of semi-annually or longer. Central service areas would be required. Frequency of body maintenance is indeterminate depending principally upon accident rates and type of vehicular usage. This work would be performed at central repair facilities or at outside body shops.

e. Overhaul of the Minicar engine is not anticipated before 75,000 miles (with scrappage at the end of 150,000 miles). Central repair facilities would be required for overhauling both the engine and the transmission.

f. Emergency Service vehicle is designed to handle on-the-road emergency work. The service truck would be designed to perform the following functions:

- Tow Minicars
- Pick up a disabled car and take it to the central maintenance facility
- Refuel Minicars
- Replace battery packs
- Change tires (i.e., replace entire wheels)
- Perform minor repairs
- Supply customer with a replacement car

#### 4. Maintenance Systems

In addition to the diagnostic systems summarized under section 3a, three basic vehicle maintenance systems were developed and compared. They are briefly described here.

a. Fixed Equipment System. In this approach emphasis is given to maximum use of simple non-automated fixed equipment located in each terminal for routine inspection and service. Major maintenance, body, and overhaul facilities would be located in a central service area. If there is little vehicle turnover during the hours an attendant is not there, it will be possible for all cars to receive regular service after each trip.

Although there may be considerable savings in the cost of equipment development, the amount of needed equipment is high. This cost may be reduced by a modification of the system which would have attendants and service installations at only major terminals.

b. Mobile Equipment System. The principle of this system is the use of specialized mobile equipment moving between terminals on regular routes servicing the vehicles within the terminals. A service truck would clean interiors daily. Routine service (except interior cleaning) and inspection would be handled weekly (or more frequently when necessary) by a fuel and parts truck towing a special lightweight washing unit.

Minor maintenance would be done in each terminal repair area by a specially designed service vehicle. As in the fixed system, major work would be accomplished in a central service area.



The number of personnel required for the operation of the mobile system is considerably reduced from the requirements of the fixed system. The equipment could be operated on a 24-hour basis partially offsetting the high cost of development and acquisition. The cars would not receive an inspection or servicing after each trip. Extra demands would be placed on the information system to locate cars which need service, direct customers to park vehicles in service areas and locate full and empty terminals.

c. Random Motion System. This approach to maintenance utilizes the random motion of the vehicles to move the cars to the maintenance facilities. Thus, it is possible to locate fixed service facilities in only a few terminals and still provide a high probability of servicing the cars at the required intervals. In order to estimate the feasibility of using the random motion of the vehicles, detailed predictions were made on how the vehicles move within the System. From the estimated motion study it was shown that one central terminal would be sufficient to handle all minor maintenance within a specific area. Such a facility would have a high capacity lane with the latest diagnostic equipment.

The cost of service equipment within each terminal would be minimal. The major diagnostic and maintenance facilities would require development cost but few would be required. The number of personnel is much lower than the fixed system and approximately the same as the mobile system.

Careful study of the projected flows of vehicles within each proposed MTS is required to take full advantage of the normal vehicle movement, otherwise a high number of cars would not receive the service required.

d. Conclusions. Each of the systems has advantages and problems that must be carefully evaluated before final conclusions can be reached. The fixed System has personnel in the terminal to handle customers problems which could be a great advantage, particularly when the MTS is first put into operation. The Mobile System reduces the cost of terminal installation and personnel; however the equipment cost is still high and the flexibility of the Fixed System is lost. The Random System reduces both labor and equipment cost and simplifies most terminal installation, but requires careful and reliable vehicle movement predictions. Each MTS must be analyzed individually to ascertain its optimum maintenance system, which could be one of these basic approaches or a combination of selected features from more than one.

## Technical Supplement S-VI

### AN MTS FOR LOW INCOME AREAS: DEMAND ESTIMATES, FEASIBILITY AND DESIRABILITY OF THE SYSTEM

#### A. Introduction

This Supplement presents results of a study about the potential application of a Minicar Transit System to a low income area, and is a summary report of a larger study [T-16]. The area selected to carry out this initial exploratory study was the low income area in the center of the City of Philadelphia. The essence of study effort was to produce a set of reasonable estimates of the extent to which the MTS might attract users and to establish an initial notion about the desirability and economic feasibility of such a system for the low income areas of the central city.

#### 1. The Problem

Any systematic and reasoned projection of the trips which an MTS may attract contains a considerable amount of uncertainty. There are two main causes of this uncertainty. First, every projection process involves a complex extrapolation of present forces and influences onto a future state, years removed from today, enriched with many new forces and encompassing many changes of the present forces. Second, there is in this case the additional uncertainty stemming from the lack of experience with the response of urban residents to an MTS. In addition, the projection must take place well before we know with sufficient clarity and certainty the characteristics of the services to be provided, the circumstances within which the provision will take place and the impact that an MTS can or would produce. Therefore, the projection process must be carried out, to a large extent, on the basis of a set of generalized assumptions about the characteristics of the System and the set of circumstances, within which the new System will, presumably, operate.

In order to facilitate the process, two dates and a specific region were selected. The dates were 1960 and 1975. For 1960, the estimates would indicate: "What could happen if an MTS were then available?" For 1975, the estimate would indicate: "What would probably take place if such a system would then be available, all other things being as planned or expected in the region?" The selected region for the test estimations was the Philadelphia metropolitan area. The reasons for this selection were simply that, first, the research team had considerable familiarity with the

problems, data banks, and plans for the Philadelphia SMSA; and second, that, from the very beginning of the Minicar Project, it was agreed that a region like the Philadelphia SMSA was an "appropriate" region for an MTS.

Finally, within the Philadelphia SMSA, the emphasis was placed first on the potentialities of an MTS in the Central Business District of the region, and then on the potentialities and limitations of the MTS in or for the low income areas of the region. At the concluding parts of the investigation, the potentialities of an MTS for the remaining areas of the region were briefly examined. No effort was applied as part of this specific study to estimating Minicar demand on the part of any special major user (post office, delivery services, etc.).

## 2. Theories and Methods in Travel Demand Estimation

There are in essence, two approaches in projecting or estimating future travel demand for a system. First, is the direct approach, or "survey method" that is utilized in projecting demand for any new commodity and is utilized extensively by market analysts. The essential element of this approach is an ad hoc survey of a carefully selected population sample. In general, a description is given of the product and the sample population is asked under what circumstances it will make use of the new product. The careful controls of the survey permit then a rather simple extrapolation of "demand" and "circumstances." A "demand estimate" and a "market area" is hence established and is provided to the manufacturer as a guide in production and distribution of the product. A "product clinic" is also, on occasion, put to use when the new product is considerably different than an existing one, or when the reliability of the responses that a regular survey would produce is considered below acceptable levels.

A second approach has been in use in the transportation field and is characterized by its total reliance on "manifest preferences" (instead of expected preferences of the market analysis survey) and on extrapolation and inference of choice based on similarity of circumstances among similar systems. This approach utilizes first a "blanket" survey of a region with emphasis on what has been the actual choice of the user yesterday. Then, by relating this choice to the relative system characteristics (i.e. cheaper, safer, faster, etc.) to the characteristics of the user (i.e. income, education, age, etc.) and to the area characteristics (i.e. density of development, slope, elevation, etc.) a general relationship is established between choice of mode, on one hand, and characteristics of the system, the area, and the user, on the other. This general relationship is used to simulate choice

patterns of any additions, variations or alternations of the system, as long as the changes can be measured on any systematic system variable (i.e. system characteristics such as cost, speed, safety, convenience, comfort, availability, reliability, etc.).

The Minicar Project tried to utilize both approaches in producing a reasonable estimate of future travel demand. Partial "test surveys" were carried out on some population segments with variable controls and limited utility in deriving generalized conclusions or developing parameters for specific, limited use of an MTS. Also, an experimental "product clinic" was held to ascertain a "first round" of reaction from "selected publics" such as specific groups of potential users, public officials, the transit, taxi and transportation industry, the intellectual community and the communications media in general. The inconclusiveness of these experimental efforts, the cost of a "total market analysis" approach, and the difficulty in communicating to the public the essential differences of an MTS has reduced this approach to the role of providing supplementary check points and insights for specific markets.

The major effort, therefore, was a "transportation planning method" that attempted to utilize the intelligence which was available, i.e. the data on manifest modal choice in 1960 in this region. This approach relies, of course, extensively on an assumed future similarity of urban transportation systems in their essential functions of transporting people and goods measured along essential system characteristics, such as total travel cost, travel speed, safety, availability, convenience and comfort. The treatment of these factors is, of course, a difficult and complicated problem. Nevertheless, it is a problem that has to be faced by all studies that attempt to relate system influence to travel preferences. The present MTS study faced this problem by producing a simplification of the problem itself and by utilizing all the empirical data that was available in the study region. Thus, the comparative measures were essentially developed on the basis of a single comprehensive variable (total travel cost) that encompasses out-of-pocket travel costs, travel time costs translated into dollar equivalents, plus associated travel costs such as waiting and walking time, depreciation costs and operating costs. The data from which these measures were derived was primarily empirical data properly reported by various study groups. No "dummy" data was utilized nor were "composite" variables incorporated corresponding to qualitative system attributes such as amenity, comfort or convenience.

The methodological dilemma also included a choice between the utilization of either an exact numerical-statistical relationship (i.e. a mathematical equation), or a relationship that was primarily graphic and

generalized. After considering all aspects of the problem the choice was made in favor of a graphic method that focused on average relationships and thus avoided the pretense of undue accuracy and specificity.

## B. Low Income Study Area

### 1. General Study Area

a. Problems of Boundary Selection. The selection of a study area introduces a number of standard and recurrent problems. The most common is the interdependence of a study's objectives with the properties of the area to be studied. In principle, a study's objectives determine the boundaries of the study area. However, in practice, the area selected often influences the study's findings, and this in turn may affect achievement of the study's initial objectives. Another problem involves the conflict between a study's goals and the availability of data. In both size and content, existing data units rarely satisfy a study's formal goals completely. A third problem centers around the conflicting demands of comprehensiveness versus specificity in the level of analysis. This can become especially severe as the number of analyses increases and it is rare for any multi-faceted study to be completed entirely within the bounds of any one study area.

All the above problems exist in this study. The first, the interdependence between the realization of the study's goals and the area selected for study, is encountered immediately within the definition of a "Low Income Area," since this affects not only the boundaries of the study area but also the size and perhaps the form of the MTS services being developed and analyzed. This problem is resolved by using a conservative definition of poverty so that services developed for such extremely deprived areas should be readily transferable to similar but less deprived areas. However, this practice has very definite limits so that it is only a partial solution.

The second problem, the conflict between the study's objectives and the availability of data, is resolved in the following manner. The principal data sources are the U.S. Bureau of Census, the U.S. Department of Labor, and the Penn Jersey Study. Unfortunately, all three have different units and levels of aggregation, and are therefore almost totally incompatible. For the purpose of this study, the most useful and comprehensive information is provided by the Penn Jersey Study since it is the only source to relate both travel and socio-economic data. Consequently, this is used as the primary and the other as secondary sources.

The last problem, the appropriate level of analysis, is more difficult to resolve. In the first place, although specific boundaries are required for any analysis, travel patterns cannot be similarly bounded. As a result, neither the impacts nor the benefits can be limited to the confines of any particular study area. Similarly, many inputs such as employment or recreational opportunities, can only be assessed over a much wider area. The system's financial and economic implications extend far beyond the area directly served by the system. Thus, it becomes necessary to identify one principal study area in terms of the study's objectives and to then examine a number of subsidiary study areas.

b. Regional Boundaries. In practice, almost every phenomena requires a different study area - see Figure SVI-1. For example, in the analysis of employment opportunities the study area consists of the seven counties in the Philadelphia SMSA. When examining socio-economic characteristics, the study area becomes a low income fringe region encompassing the CBD. In the study of shopping and recreation, the study area constitutes a somewhat broadened low income fringe. When it comes to the analysis of travel demand, the study area becomes a two-tiered unit in which the inner tier corresponds to the low income fringe around the CBD and the outer tier corresponds approximately to a maximum trip length of 12 miles from anywhere in the low income fringe areas. More specifically, the boundary is determined by the number of home-to-work trips originating in the study area and ending in the region so that the actual boundary reflects existing and projected land use patterns.

Although a number of study areas are used, they all have a common core, namely, the low income fringe around the CBD. On account of its overwhelming importance throughout all these analyses, this central core is designated the formal study area. Its selection is critical to the success and objectives of the study and must therefore be chosen with particular care. The other study areas are treated more informally and are integrated into the analysis only as far as they are related to the specific phenomena under examination.

## 2. The Formal Study Area (Low Income Area)

a. Poverty Indicators. There are three primary concerns in selecting the area to be studied. The first is that the area be sufficiently general for the results to be transferable to other cities. The second is that the majority of low income areas in Philadelphia be included so that the most realistic travel demand estimates can be prepared. And the third is that no area be omitted which could affect the conclusions of the study.

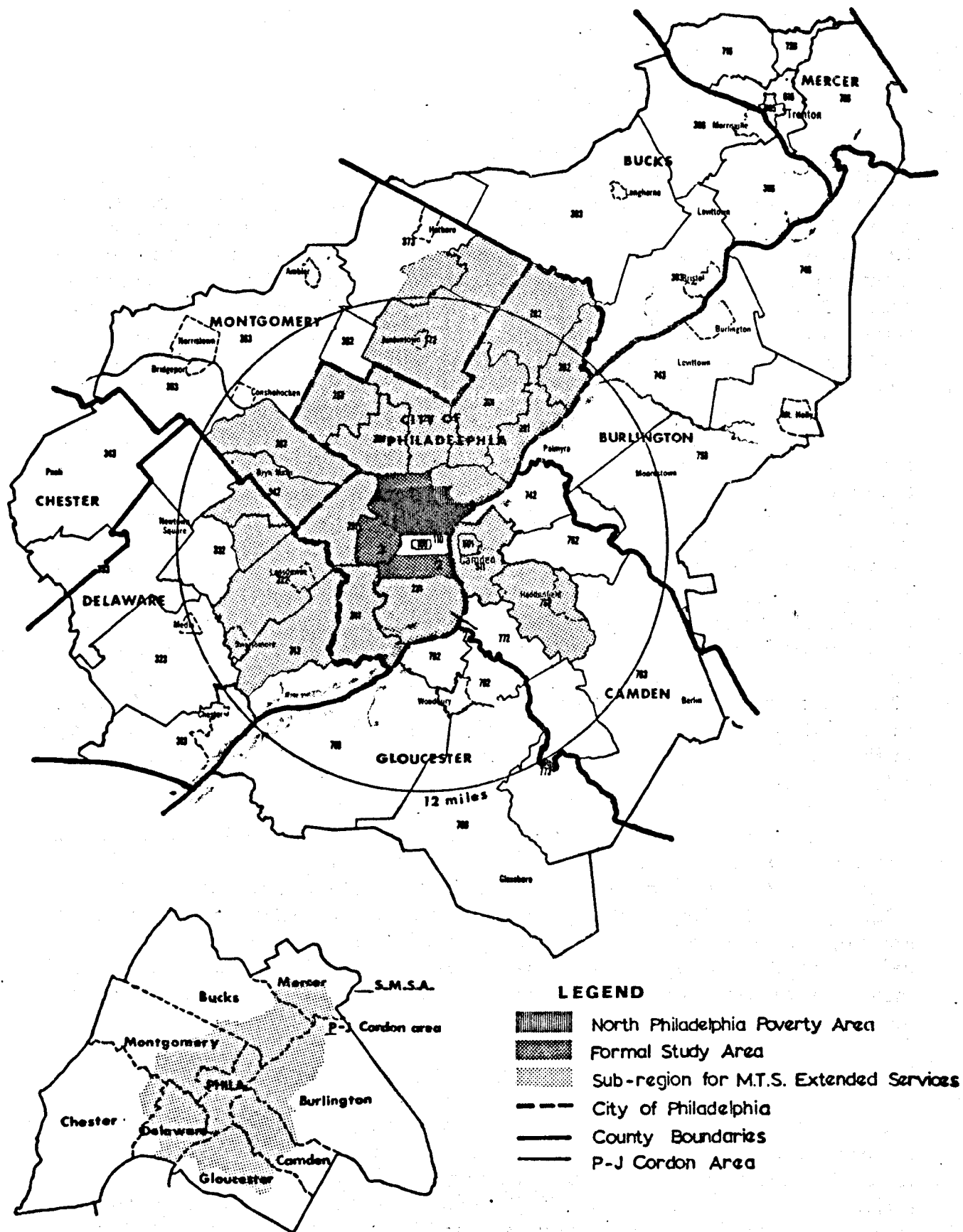


FIGURE SVI-1. THE PHILADELPHIA REGION

Certain areas are unavoidably excluded: Camden for legal reasons; others, such as Southwest Philadelphia, because they are not contiguous with the CBD and the principal system; and others because they are small pockets.

Since the formal study area is selected primarily on the basis of the poverty of its residents, a number of reliable parameters are required to indicate the most poverty stricken areas. These are not intended as absolute definitions of poverty but as measures which will ensure the inclusion of all characteristic low income areas in Philadelphia.

Three criteria: income, employment, and educational attainment are identified by the Health and Welfare Council in Philadelphia as being the key parameters of an area's deprivation [B-22]. However, since there is no universal standard for any of these criteria, each study must set its own particular levels according to its best interest. For example, an employment oriented study, [B-19, p. 8], defined the "Annual Cash Income Threshold to Poverty" as varying between \$1,540 for a single person and \$7,635 for a family of thirteen if resident in non-farm areas. Clearly this definition is too sophisticated for this study, particularly since data is only available for median household income on a real basis. The OEO definition of poverty is simpler, namely a household income of less than \$3,000 but it raises a different problem. If this definition were applied to the median household incomes found in each of the Penn-Jersey Study Districts, Philadelphia would have no low income areas at all. This is such an obvious misstatement that the OEO definition cannot be regarded as suited to such aggregated measures of income. Consequently, new and perhaps unique values must be established for each study. Those used here necessarily relate very closely to their Philadelphia context and as such are not directly transferable to other cities.

Level of Income is set at \$4,000 for the 1960 median household income of a Penn-Jersey Data Collection District. This includes approximately the lowest quintile income group in the City of Philadelphia which is the index of poverty used by the City's Planning Department. It also coincides with the level at which considerable data in the Penn-Jersey Study is subclassified.

Level of Employment is set at 9% unemployment since this is twice the national average in 1960\*. This rate is known to conceal a

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\* This is the standard measure of unemployment which is further defined and related to subemployment [T-15d, 4(a), (b)].



considerable amount of subemployment but this index was not measured in 1960\*.

Level of Educational Attainment is set at less than tenth year of high school completed.

b. Study Area Boundaries. On the basis of the preceding indicators and the stipulation that the study area makes operational sense for the Minicar Transportation System, the area finally selected is shown in Figure SVI-2. It consists of three naturally bounded areas in North, South and West Philadelphia. These areas stretch between the Schuylkill and Delaware Rivers, and between the Vine Street Expressway and Allegheny Avenue and the vicinity of Germantown Avenue in North Philadelphia; between the Schuylkill and Delaware Rivers, and South and Morris Streets in South Philadelphia; and between the Schuylkill River and 49th Street, and between Fairmount Park and the railroad tracks by Grays Ferry Avenue in West Philadelphia.

c. Study Area Characteristics. The formal study area consists of eleven Penn-Jersey Data Collection Districts with a total 1960 population of 540,243 and an overall median household income of \$3,792 (see Table SVI-1). This compares with a population of 1,949,538 and a median household income of \$5,927 for the City of Philadelphia. Between 1960 and 1975, the area's residential population is predicted to decrease by 6% and the median household incomes to rise by 46%. In the same time period, the City of Philadelphia is anticipated to experience comparable changes of 4% and 45% so that the relative socio-economic status between the city and the study area is not expected to change significantly.\*\*

The analysis of the 1960 unemployment rates for the City of Philadelphia and the formal study area indicate that the rate in the study area is above 9%. Those few pockets of the study area which have significantly lower rates are concentrated around major educational institutions and the Italian sector in South Philadelphia.

In terms of educational attainment, the study area is almost solidly composed of adult persons who, on average, have not completed 10th grade.

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\* The concept of subemployment was developed by the U.S. Dept. of Labor in the mid-1960's to cover the entire employment hardship area. It is particularly concerned with low wages, part-time employment, permanent dropouts from the labor force, who are all excluded from the conventional measure of unemployment. For a more precise definition of sub-employment, see [T-15d, 1(d)].

\*\* Whether or not these forecasts are accurate is not yet known. There is some evidence to suggest that the growth rates in the study area have differed from those recorded here but as yet there is no conclusive evidence to confirm or reject this trend.

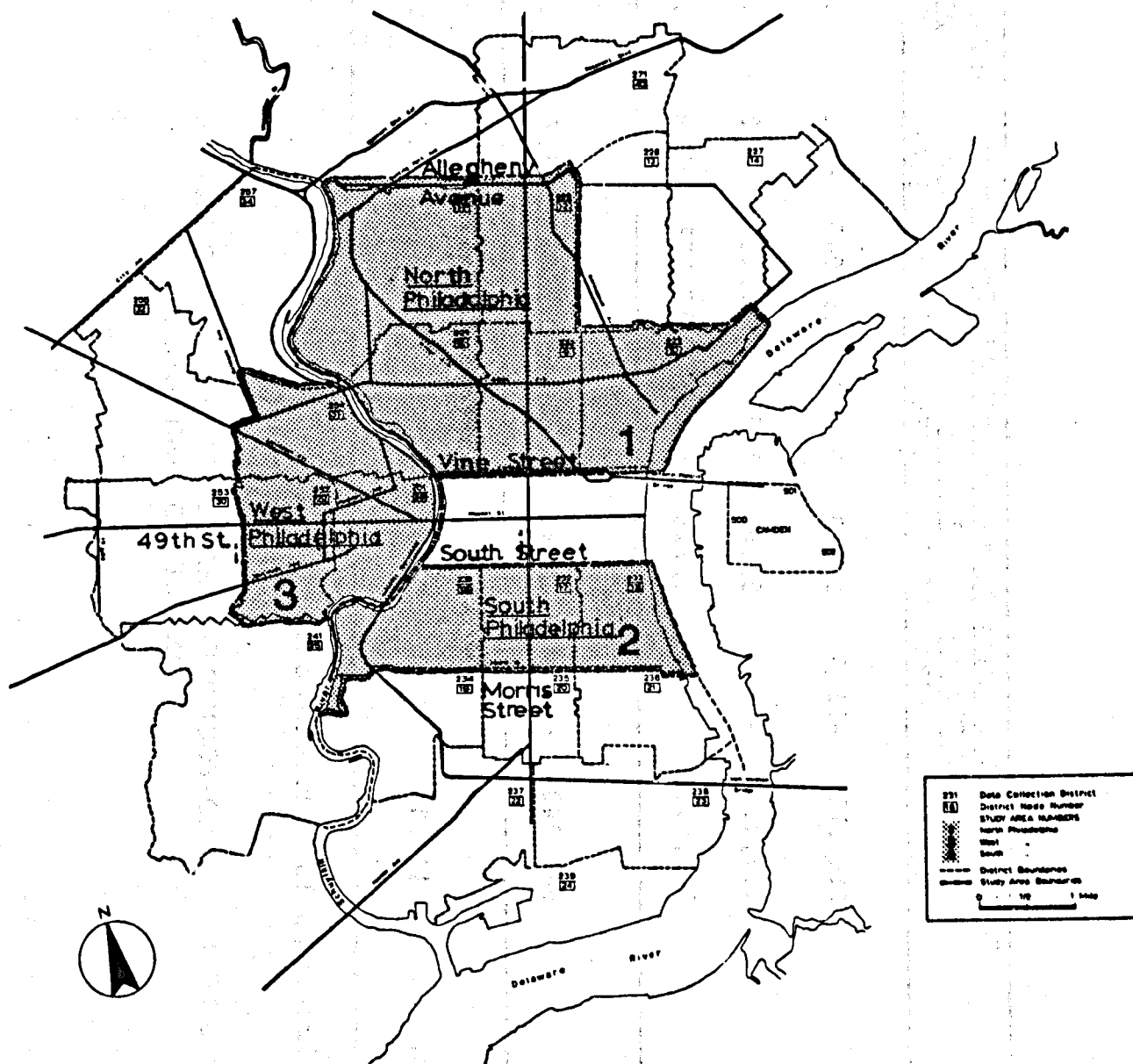


FIGURE SVI-2. THE STUDY AREA

AREA	<u>Residential Population</u>		<u>Median Household Income</u>		<u>Employment % Change</u>		<u>Auto Ownership per person</u>	
	1960	% Change 1975	1960	1975	1960	1975	1960	1975
North Phila.	315,111	-11.6	3,793	5,400	131,040	-3.1	.12	
South Phila.	122,159	-12.9	3,851	5,600	37,192	-2.2	.14	
West Phila.	102,973	4.5	3,718	5,850	58,052	22.8	.17	
Total Study Area	540,243	-8.8	3,792	5,550	226,284	3.7	.14	
Total City of Phila.	1,949,538	3.89	5,927	8,570	875,519	12.9	.22	

SOURCE: Reference [ T-16, Tables A-1 and A-2 ]

Table SVI-1. SOCIO-ECONOMIC CHARACTERISTICS OF FORMAL STUDY AREA  
AND CITY OF PHILADELPHIA

It also contains three large pockets whose average years of schooling completed is less than eight years. These are special problem areas because they contain unduly large numbers of unskilled, illiterate persons who have only recently migrated to the city from the country. The only exception to this widespread lack of education is in West Philadelphia and results from the presence of university students.

### 3. Socio-economic Opportunities in the Region

Within the larger study area the following socio-economic opportunities will tend to become available to Minicar users if appropriate services become available.

a. Employment.\* Employment opportunities abound throughout the Philadelphia region which is one of the largest and most diversified industrial areas in the world. Since 1960, there has been a rapid expansion of its science oriented firms and its service industries, particularly in government, real-estate, education, finance, medical and personal services. This growth trend in the "knowledge" industries is not found in manufacturing industries which have declined severely in the City of Philadelphia - see Table SVI-2.

Table SVI-2

#### PROJECTED NET CHANGE IN NON-FARM WAGE AND SALARY EMPLOYMENT IN PHILADELPHIA SMSA, CITY. AND SUBURBS: 1960-75

Industry	Philadelphia SMSA	Philadelphia City	Philadelphia Suburbs
Non-Farm Wage & Salary	+450,300	+154,400	+295,900
Non-Manufacturing	+408,500	+163,600	+244,900
Manufacturing	+ 41,800	- 9,200	+ 51,000

Source: U.S. Department of Labor, Manpower Administration, "Manpower Planning Report for The Philadelphia, Pennsylvania Area" Bureau of Employment Security of Pennsylvania, June 1968.

\* For a more detailed description and analysis of employment in the Philadelphia region, see [T-15d].

At the same time, the low skilled labor force has expanded considerably through a continuing in-migration from more rural areas so that there is now a deficiency of low skilled jobs in the city and a surplus in the suburbs.

These considerations, together with the employment and manpower projections prepared by the Pennsylvania Bureau of Employment Security, indicate that as many as 15,300 subemployed persons could benefit directly from a reverse commuting service - see [B-3]. Others already fully employed might benefit indirectly by using such a service to better their jobs, although this movement is not expected to be insignificant because so many of the better employment prospects are in the city rather than the suburbs. Still others will gain by diverting to a more convenient mode of transportation. Of course, many of these first group of potential subscribers would critically lack driver's licenses or would find employment in the city so that only a number around 8000 latent reverse commuters can be expected to form a "market" by 1975 - see [T-15d, 5].

The new employment opportunities can be located almost anywhere in the region since almost every suburban area is expected to grow considerably by 1975. However, opportunities for low skilled persons and ghetto residents tend to be located in certain industries or where there are particularly high rates of growth. Jobs must also be within reasonable commuting distance so that transportation costs are not excessive. This and related data can be applied to the Penn-Jersey Study employment projections to give the maximum probable employment opportunities for ghetto residents in 1975. The total number of job opportunities that appear probable and appropriate for low skilled workers is approximately 28,800 which represent jobs far in excess of the number of ghetto residents able to make use of them. Thus the location of new employment opportunities for ghetto residents is likely to present few problems. Consequently, the MTS can afford to be selective in the areas it serves since the supply of commuters is limited.

b. Shopping. Two types of shopping facilities would become available to the Minicar user; those in downtown Philadelphia and those in the suburbs. The former are already accessible on transit but tend to be inconvenient; the latter are generally inaccessible to all but the auto or the potential Minicar user. This would enable more persons to avoid the high-priced, low-quality merchandise that characterizes many stores in low income areas.

c. Recreation. Recreation facilities can be classified as either outdoor or indoor. The former cater principally to the more athletic needs of the population, such as competitive and water sports, walking, golf, etc. The latter, though including some sporting activities, tend to be more artistic and educational in nature. They may be either programmed, e.g. a concert, cinema or nightclub, or non-programmed, such as an exhibition, a library or a historic building. In terms of provision, outdoor facilities are generally supplied at a regional level by park commissions and at a neighborhood level by the local governmental units. With few exceptions, facilities in the first group are accessible only by auto, but those in the second group can also be reached by transit or walking. In general, a Minicar System will make accessible to its users numerous regional recreational facilities indoors and outdoors, in the central part of that region and in its inner suburbs.

#### 4. Transportation Facilities and Services in the Formal Study Area

a. Roads. The road system in the formal study area consists principally of a rectangular grid of arterial and lesser streets with only the Schuylkill and Vine Street Expressways offering freeway access to the region (see Figure SVI-3)\*. The average speeds in 1960 (both peak hour and off peak) were between 15 and 19 mph for most of these routes (see [B-21a, Maps 47 and 48, p. 111-112]). Except for Broad Street, the principal arterials tend to have only minimal delays (see [B-21a, Map 51, p. 114]). However, within this arterial grid, many streets are narrow and have very limited capacity. They are further congested by very dense curbside parking, because of an almost total lack of off-street parking facilities. In general, the road system is barely adequate for present needs and would require extensive improvement if levels of auto ownership in the area were to increase sharply.

b. Transit Services. The transit system within the City of Philadelphia is generally regarded as one of the best in the nation. It consists of two major subway lines running north-south and east-west, subway-surface routes and bus lines. These routes provide an intensive coverage throughout the entire formal study area but almost all are oriented toward the CBD. As a result, accessibility along the axes is generally excellent but most other trips require at least one time-consuming transfer, (see [T-15b]). In some instances, particularly in West Philadelphia, travel between quite close areas is impossible without either a very long and circuitous route through the CBD or extensive walking. This is a characteristic failing of virtually every form of transit so that Philadelphia's weakness in this respect is not atypical.

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Construction on Highway I-95 to the northeast is just commencing.

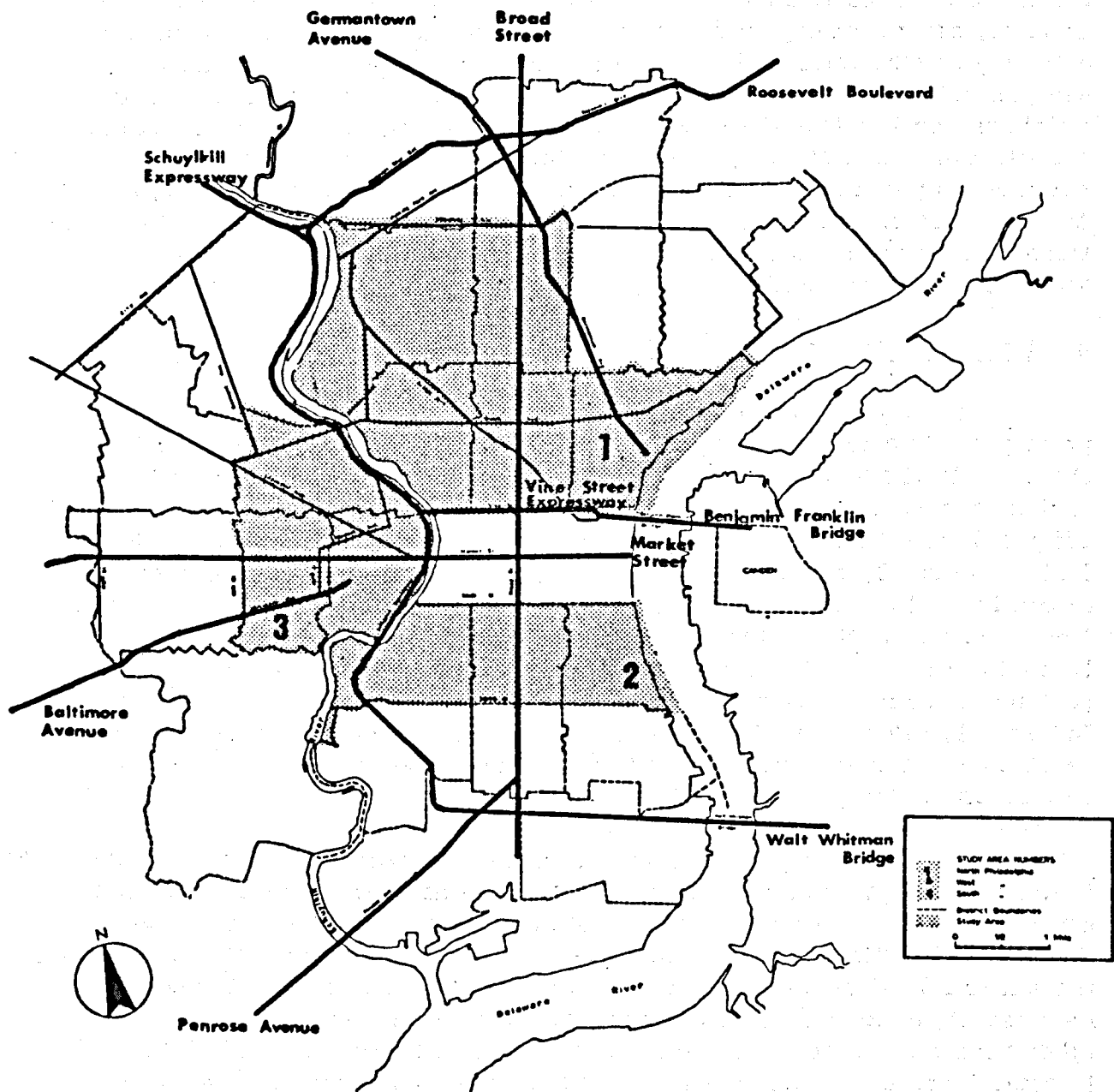


FIGURE SVI-3. ROAD SYSTEM

In terms of overall frequency of service the entire formal study area has an excellent service although particular routes, especially cross-town, have some very infrequent schedules. In general, the number of transit vehicles per sixth of a square mile ranges between 250 and 450 per 17 hour day for most areas, increasing to between 600 and 700 a day for those areas served by subway. The only exceptions are Fairmount Park, which is virtually unserved, and parts of West Philadelphia south of Market Street which have an exceptionally high level that is largely due to the presence of a number of very fast underground streetcar routes. However, despite this frequency, trips by transit from low income areas tend to take at least twice as long as comparable trips made by auto. This pattern is repeated throughout the study area and shows very clearly the travel restrictions placed on transit users. Except for those areas served by subways or railroad, this disadvantage tends to become more acute with distance so that the desire to make longer trips is very quickly inhibited.

#### 5. Travel Characteristics of the Residents of Low Income Areas

One of the most powerful influences on travel characteristics is auto ownership - see [T-15a]. Typically, levels of auto ownership increase with income and decrease with higher densities. Both the Philadelphia region and the formal study area (low income areas) follow this general pattern. The car ownership rate of the formal study area is far below that of high income areas, and even lower than the regional average.

Trip generation in the Philadelphia region and the low income areas (the formal study area) follow expected patterns. Rates for total trips decline steadily as the 1960 median household income falls from \$8,000 to \$3,000. Rates for auto trips drop more sharply between \$7,000 and \$5,000, while rates of transit trip generation grow until they peak at approximately \$3,000 (see [T-15 a, Fig. 1.11]). Below this figure, all trip generation rates fall, indicating a breaking point below which the socio-economic groups experience a serious decrease of mobility.

The study area is characterized by some of the lowest rates of auto trips in the region. This is, of course, not surprising considering the level of income of the study area.



### C. The System Tested

Chapter II of this Report describes the MTS in terms of general system characteristics. Beyond this description, it is important to visualize an actual System before demand estimates can actually proceed. Such a System is, of course, bound to be a very unspecified one at this point of time, but nevertheless, it should include all the characteristics that would make it an actual running System, able to compete with other systems existing or proposed. In other words, terminals must be thought of, fares delineated, walking distances and waiting times taken into account, etc., before a MTS can become a real enough concept to be studied for a real city.

The following system definitions were made only for the purpose of this study and although we believe them to represent realistic expectations, they should not be considered as binding in any manner or form.

#### 1. Services Examined for Low Income Areas

The task of the present study is to examine the feasibility of extending or modifying a CBD oriented MTS to serve low income areas, particularly those surrounding the CBD. Four important characteristics this System should have in order to insure its utilization are:

(i) Fare Structure: A single trip-rate for the entire System cannot allow for different auto operating and parking costs in different areas of the city. It is therefore proposed that the fare structure be amended to consist of a variable charge per terminal for each entry and exit, plus a greatly reduced mileage and time charge. This fare structure contains an inbuilt minimum charge to prevent excessive diversions from transit. It can also be used to subsidize travel to and from particularly depressed areas by reducing or even eliminating appropriate terminal charges.

A further extension which would have a very considerable impact on the temporal structure of travel demand would be to vary terminal charges by time of day. Different rates could be set for peak-hour, day-time and evening entries and exits so as to regulate travel demand for the system.

(ii) Methods of Payment: Neither monthly billing nor advance cash payment are likely to be well received in low income areas. The former is not yet a widely accepted method of payment and the latter is not trusted. It is suggested that weekly billing or direct cash payment into a burglar-proof strong-box at the destination terminal be offered as an option in low income areas.

(iii) Shared Trip-Rates: The use of cash payments at the destination terminal would allow for partial payment by the passenger and would therefore encourage shared use of the Minicar. If so desired, it could also be adapted into a method of direct cash payment.

(iv). Shared Flat-Rates: Problems of payment for Minicar use similar to those mentioned in (ii) and (iii) above exist with the reverse commuting service for low income persons. However, the method of payment and administration required should be considerably easier to arrange than for shared trip-rates.

In terms of services to be studied the following individual and combinations of services have been examined:

a. Extended Trip-Rate Service (ETRS). This service is an areal extension of the principal trip-rate service (see [R-1]) into Philadelphia's low income areas. The two services are considered fully integrated with no distinctions between them at any level. Except for those changes recommended above, (which should be introduced into the entire system rather than one isolated part), the extended trip-rate service will operate precisely as the principal trip-rate service is currently envisaged.

b. Reverse Commuting Service (RCS). This service complements the flat-rate service (see [R-1]) of the principal system. Instead of being CBD-oriented, the reverse commuting services would concentrate on the inner city resident who works in the suburbs. Like its counterpart, this service would be extremely dependent financially upon the success of complementary day-time use. However, unlike its counterpart, it need not be operated on a flat-rate basis. Many forms of fare structure are available. Fares could be per person or per car; they could be computed on an actual mileage basis or presented as round trip fares.

One interesting operational feature of this service is that it could operate exactly as a completely reversed flat-rate suburban commuter service, i.e. there is absolutely no operational need for a network of terminals in low income areas\*. This feature could become quite important if for some reason the reverse commuting service is to be implemented before the extended trip-rate service.

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\* Terminals may be necessary as a means of combating vandalism but this decision would be the result of a trade-off between vandalism costs and terminal costs.

c. Limited Trip-Rate Service (LTRS) (Supplementing Reverse Commuting Service). The essential difference between this and the reverse commuting service described above is that terminals would definitely be located in the low income areas. This would enable the vehicles to be rented out to other subscribers during the evening and weekends. It would, therefore, be of much greater value to the local communities with correspondingly greater social benefits. These would be increased greatly if the evening and weekend services could be operated with minimal fares. For example, hourly leasing plus a small mileage charge would be most likely to stimulate demand for this service, particularly during weekends.

d. Additional MTS Suburban Services. All the extended services imply the introduction of a number of complementary suburban based services to increase vehicle usage. The simple extended trip-rate service would have vehicles lying unused at night; these could be used for a suburban commuter service (SCS) just as the trip and flat-rate services in the principal system complement each other. Similarly, the reverse commuting service needs supporting daytime suburban service (DSS) for individuals, firms, or commercial establishments. These latter services could take many forms but demand for them is not assessed here because they are considered secondary to the low income area services, and depend excessively on MTS policies. The demand from large fleet-users is being examined elsewhere but there may also be a heavy demand from small, under-capitalized suburban firms and shops that need to operate a day-time delivery service.\*

Another potential suburban user is the housewife whose husband has to use the family auto to get to his job. Many women in this category are completely stranded at home during the week because of the absence of a second auto and adequate transit or taxi service. Such persons might be very receptive to a scheme that would enable them to lease the Minicar on a regular one day a week or more basis. This service would be even more attractive if the Minicar could be delivered to their door by the same method as used for vehicle redistribution. Typically, a vehicle would be delivered by 10 a.m. and picked up shortly after 4 p.m. for a total flat-rate charge of about three dollars per day.

e. Other Individual Services. Other potential services are for the first leg of a railroad or transit commuting trip (in either direction), in garages to replace cars being repaired or services, and a variety of evening and weekend uses by non-auto-owners such as the elderly and young adults. Special leasing services could be offered to hospitals and other community organizations. All these extensions to the system represent only a very small portion of the services possible. The most extraordinary and significant attribute of the MTS is its almost limitless flexibility which

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\* Mnicars, Inc. was responsible for examining the market for fleet usage.

enables it to continuously adapt to new consumer demand as soon as it arises or is discovered.

f. Combined Services. Any combination of the above individual services that are not inherently conflicting can be implemented. There are several such combinations that are rather "natural" in concept and operations; such as the ETRS with the RCS, or a combination of ETRS, RCS, parts of LTRS, plus Daytime Suburban Service, plus several specific users or fleet operators, or a simple combination of RCS and LTRS. In many respects, the form in which the system could be introduced and maintained would differ from case to case and would depend on the preferences of the individuals who are responsible for the system and the set of circumstances into which the system would be initiated and then maintained.

#### D. Estimation of Minicar Trips

There are several steps in the actual process of estimating Minicar trips from an urban MTS. In this case, six steps ought to be completed before conclusions can be reached, i.e.

- (1) Formulation of system variables
- (2) Selection of representative trips
- (3) Determination of cost ratios
- (4) Synthetic direction curve development
- (5) Manifest travel demand estimates
- (6) Latent travel demand estimates

The essential elements of the work involved in the completion of each of these steps are presented in the following pages.

##### 1. Formulation of System Variables

The task of forecasting manifest travel demand for an innovative transportation system is essentially a matter of revising the demand estimates for each mode within a constant system demand. This demand can be considered as resulting from each individual selecting the mode of transportation most appropriate to his needs after he has compared alternative sets of such modal characteristics as travel cost, time, safety, convenience, quality of service, etc. This individual decision-making process is based on the essential postulation that the actual choice between modes is modally neutral and is made on the basis of relative travel characteristics. Thus, a measurable system variable must be formulated so that the relative merits of competing transportation systems can be assessed quantitatively.

In our case a comprehensive calculation of "travel cost" appears to be particularly expressive and suited to our needs. This was also consistent with previous work on the MTS. Travel cost in this case includes all time lost and out-of-pocket costs. This raises two important problems: first, as to whether total or marginal travel costs is the more accurate basis for comparison; and second, as to what is the most appropriate value of time. Both these are very debatable issues and were resolved very similarly. In the first case, total and marginal cost comparisons represent the upper and lower bounds on the final demand forecasts; hence, the analysis is conducted for both sets of costs. The second problem is resolved by using three different values of time, \$1, \$2 and \$3 per hour which are considered to be representative of the time values for most Minicar users.

Total travel cost is defined as including all time and out-of-pocket money costs [R-4, pp. 49-50, 65-66 and 113-121]. For the auto, this consists of all operating costs (fixed and variable for the total, but only the latter for the marginal travel costs), parking costs, and the total travel time including that spent walking at both origin and destination. Transit costs are simpler and consist of the fare and total time costs (access, waiting, running, interchange, etc.). The Minicar costs are very similar except that the fare structure is now mileage-dependent and there is no interchange time. These costs are fully documented elsewhere and are perfectly standard except that both the fixed and variable auto costs are derived for each income group from the 1960-61 Survey of Consumer Expenditures by the Bureau of Labor Statistics (see [T-15e, 2(a), (b), (c) and (d)]). This is undertaken because the conventional way of estimating these costs does not usually consider the increase of fixed cost along with increases of the income of the auto owner.

## 2. Selection of Representative Trips

The next step in the demand analysis is to develop a set of "representative" trips which can be "costed" for each mode. It is a difficult phase of the analysis because of the diverse nature of trip patterns, especially for auto. The problem is magnified by the fact that truly sensitive criteria result in too many "representative" trips to analyze. Another critical factor, limiting the total number of representative trips, is the financial and manpower resources available to analyze them. The problem is further compounded by the depth of analysis required. It is very clear that travel demand for an innovative system cannot be developed for only one set of operating conditions since that would preclude consideration of a large number of options. Equally, not every option can be examined, so that some form of compromise between these extremes is necessary.

In practice, two sets of trips are developed. The first contains 97 actual trips which are shown schematically in Figure SVI-4.\* For ease of analysis, they are divided into four major categories:

- Intra-District Trips (Type A)
- Intra-Low Income Area Trips (Type B)
- Inter-Low Income Area Trips (Type C)
- Subregional Trips (Type D).

These trips are identified in a number of different ways. The first step is the identification of significant travel patterns from the 1960 trip file of the Penn-Jersey Study. This information is further subdivided by trip purpose and land use so that the travel patterns can be modified on the basis of the projected changes in land use. Thus, it is possible to select trips that are representative in terms of their average length and frequency, their present and future land uses at both origin and destination, and their sensitivity to new trips.

The second set of trips is known as the "Synthetic Representative Trips" because of their statistical derivation from the previous set (see [T-15e, Tables 6A-4 and 6A-5]). These trips number only 15 and are developed in order to \*\* analyze the system's performance under a wide range of operating conditions. They are derived by grouping trips with similar cost ratios and computing their mean lengths and travel times. However, the differences in the final demand estimates derived from the larger set of trips and that of the "synthetic" trips is so insignificant (always less than 2%) that the latter set is used to develop all demand forecasts.

### 3. Determination of Cost Ratios

Cost ratios are the means by which one mode's performance is compared to another's as they serve each representative trip. The system variable is computed for each mode and then divided to give the following ratios for each trip, value of time and system operating conditions:

- Minicar/Transit Cost
- Minicar/Total Auto Cost
- Minicar/Marginal Auto Cost.

These ratios represent the comparative advantages between modes in terms of their relative user costs. Thus, when a ratio is greater than 1.00, it is less advantageous to travel by Minicar and conversely when the ratio is less than 1.00.

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\* The complete set of trips is shown in [T-15e, Figures 6.2 and 6.3].

\*\* In particular, sensitivity analyses were performed and reported in [T-15f].

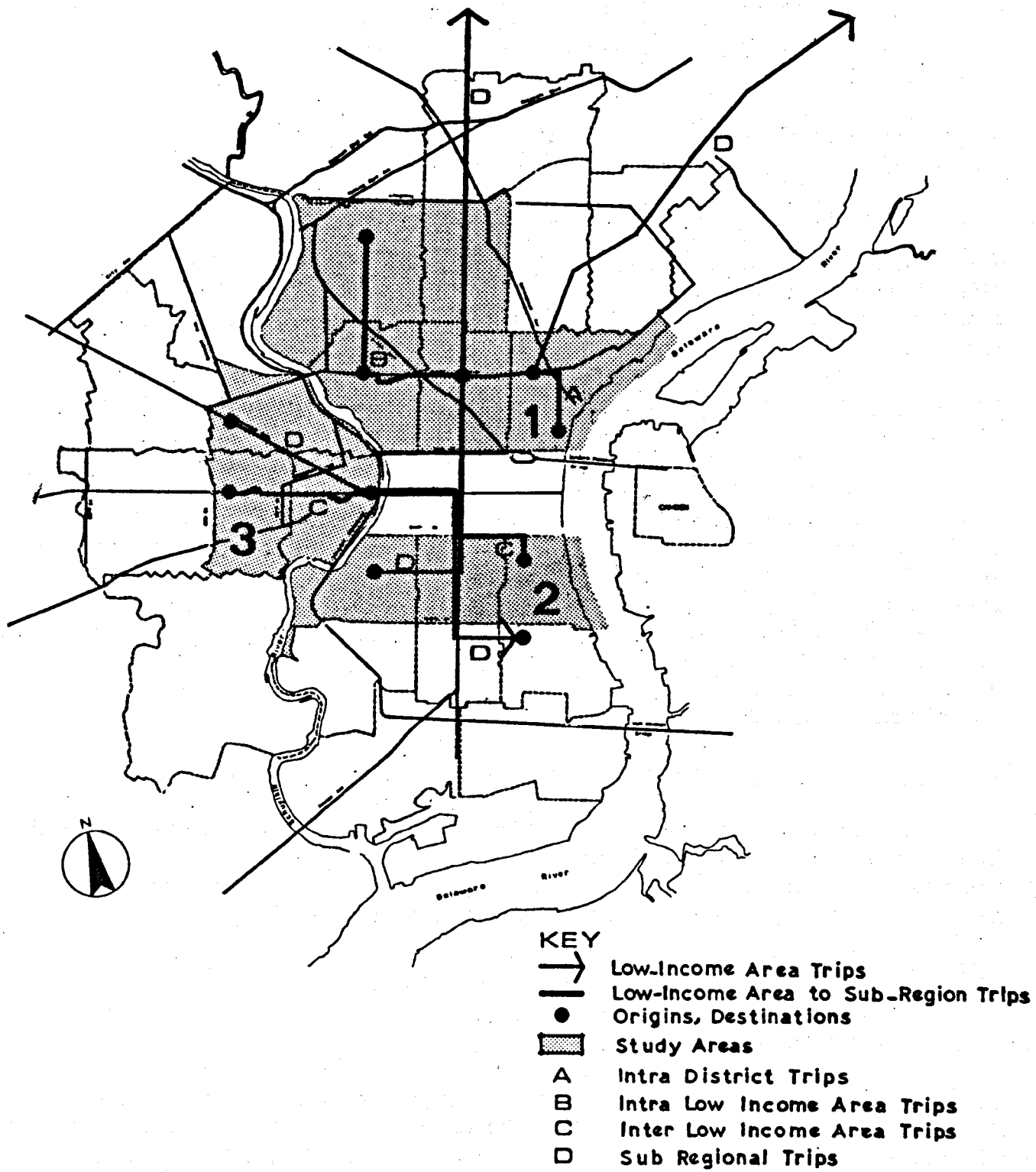


FIGURE SVI - 4. REPRESENTATIVE TRIPS

These cost ratios are computed for four alternative sets of operating conditions which are selected as representing different degrees of optimality for the system (see Table SVI-3). The Minicar fare is reduced to 15 cents and 10 cents/mile to examine the consequences of reducing the fare for trips outside the CBD. The terminal spacing is varied between 1/3 and 1 mile to determine its effects on demand, terminal size, feasibility, etc., and the auto parking cost is examined as a means of persuading motorists to divert to the Minicar. However, the particular combinations developed here are only representative of those available; many more exist and are examined in [T-15f].

Table SVI-3

SYSTEM SETS FOR TESTING

Set	Minicar Fare[¢/mi.]	Value of Time $V_t$ [\$/hr.]	Terminal Spacing [miles]	Auto Park Cost [¢]	Max. Fee on Round Trip [ \$ ]
I	20	1,2,3	1.00	---	2.00
II	20	1,2,3	0.33	10	2.00
III	15	1,2,3	0.67	10	1.50
IV	10	1,2,3	0.33	25	1.00

Source: Reference [T-16, Table 6-1].

A sample of the impacts of these conditions on the cost ratios are shown (indicatively) in Figure SVI-5. Set I is clearly the least, and Set IV the most favorable in terms of demand generated for the Minicar Transit System. In general, the ratios were found to be neither particularly sensitive to variations in the value of time nor especially consistent in the pattern of their responses. Trip length is of much greater significance although its effects are clearly dependent upon the operating conditions in each set. More specifically, the Minicar/total auto cost ratios are the most responsive to changes in the operating conditions, especially the Minicar's fare structure. Set I appears completely insensitive to different values of time and has absolutely no favorable ratios. Shorter trips show particularly adverse ratios which is most probably due to the low terminal density. Sets II and III, though more realistic than Set I, still have no ratios in favor of the MTS. The effect of the maximum fare in reducing the cost ratios on the longer trips is clearly visible but they are still too high to be truly competitive. Set IV is marginally sensitive to time but exhibits virtually no variations with the length of the trip. But for the first time, two sets of ratios for  $V_t = \$1.00$  and  $\$2.00$  show cost ratios in favor of the MTS.



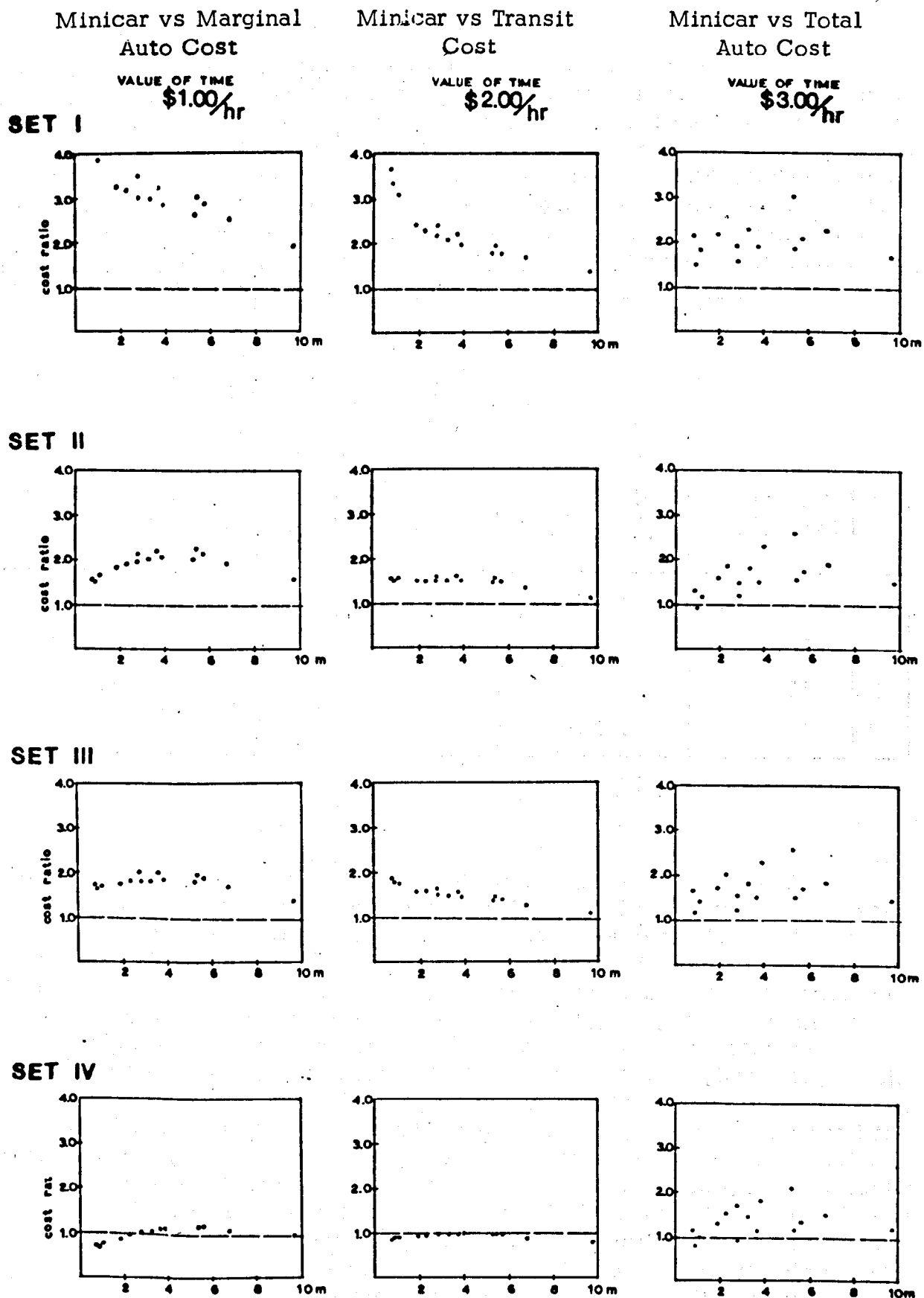


FIGURE SVI-5. MINICAR COST RATIOS

In general, all short trips of less than 2 miles and most long trips are better served by the Minicar. In contrast, most middle range trips, especially in Sets I through III, are better served by transit. The value of time always operates to increase the ratios as the value of time decreases, thus working against the lower income users. The only exception occurs for the very short trips of less than 2 miles where persons with low values of time have a marginal advantage.

#### 4. Synthetic Diversion Curve Development

The user-cost ratios described above are converted into travel demand projections through the use of diversion curves. Such curves are usually formulated on the basis of empirical data or direct experience but in the case of an innovative transportation system this is obviously not possible. Consequently, "Synthetic Diversion Curves" are developed on the basis of a set of explicit value judgments and past experience in the field of urban transportation as to the probable preferences of individuals in a number of clearly defined situations. Further, it is necessary to develop synthetic diversion curves that are suitable for modal choices within low income areas since it is highly improbable that choices in low income areas bear the same influence that choices in the CBD would have.

The first step is to consider the number of curves that are needed. In the case of low income areas, there is a need for two "master curves", one for diversion from auto and one for diversion from transit. The next step is to assess the new percentages of "non-divertible" trips. This is also a critical phase which exerts an important influence upon the final demand estimates, particularly when diversion rates are above 75%. It is an area about which more thorough research needs to be undertaken. Nevertheless, the analysis of the 1960 data with regard to car occupancy rates, percent of licensed drivers among transit riders, group size of taxi riders, etc. has provided some pertinent indications on the basis of which the rates in Table SVI-4 have been determined.

The actual diversion curves are formulated by establishing five decision points for each curve. The first point is established by estimating what proportion of the divertible trips will be diverted when the travel costs are equal for both modes, i.e. when the cost ratio equals one. The next step is to estimate the cost ratios at which 10% and 90% of the divertible trips will be diverted to the MTS. The final step is to establish boundary conditions. The prevailing belief in developing these forecasts is that low income persons tend to be more sensitive to minor cost variations than any other group. This tendency may be hindered by a limited awareness of other opportunities including the Minicar, but this should be less of a problem amongst licensed drivers. As a result, only minor changes are made between the daytime diversion curves for the CBD and those for the low income areas (see Figure SVI-6). In general, they tend to be steeper, indicating a greater cost sensitivity, and to have

longer "tails", indicating the existence of a small minority of very cost-independent persons.

Table SVI-4

Percentage Non-Divertible Trips in Downtown  
Philadelphia and Low Income Areas

Mode	Central Business District	Low Income Area	Reason for Change
Transit	60%	55%	Proportionately fewer licensed drivers amongst transit riders, which is nearly counterbalanced by a higher modal split in favor of transit
Auto	5% Salesmen	--	Salesmen are active primarily in the CBD
	5% Drivers "glued" to their autos	15%	Higher status for auto owners
	5% Parties of 4 plus	10%	More intensive use of autos
TOTAL	15%	25%	

Source: reference [T-16, Table 6-2].

The final step before actual trip estimates is to establish the trip universe on the basis of which the diversion can be calculated. This is a particularly important step because it influences the final estimates as much as all the other steps taken together. For the purposes of the tests designed for this project several universes were formed. Table SVI-5 presents the final universes and their derivation by trip purpose, mode of travel and the area within which the trips are to be made in 1975. In this table three universes are indicated, i.e. the ones determined as most suitable for ETRA, RCS, and for "other services", by mode of travel. It is interesting to note that the universe for ETRS is 461,353, for RCS is 138,518 and for other services is 718,924 trips.

#### 5. Manifest Travel Demand Estimates

a. Extended Trip-Rate Service. This service caters to all trips made within the selected low income areas and for a limited number of trips to the subregion. However, since terminals are not envisaged outside of the low income area, if this service be established alone, the latter group must be

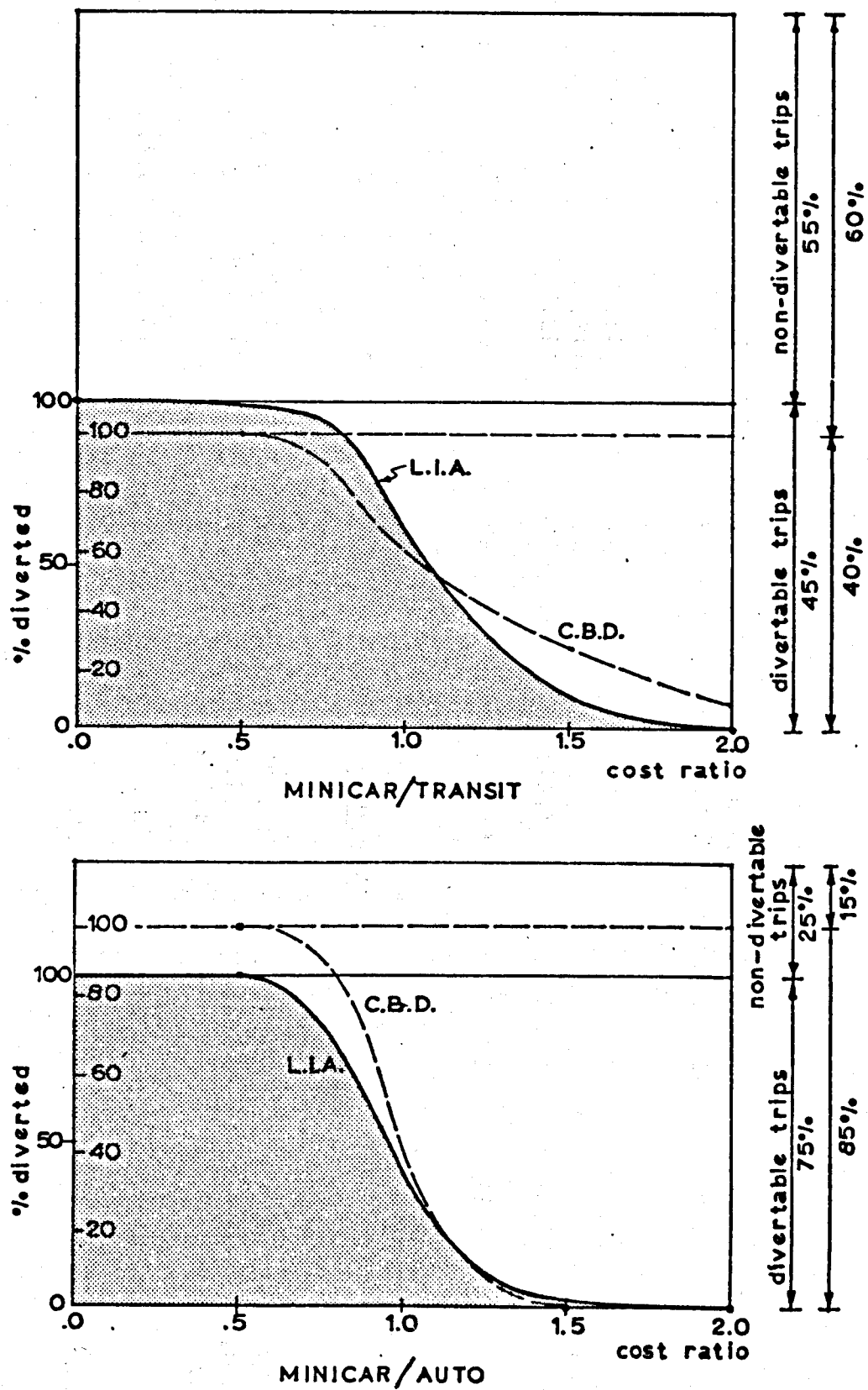


FIGURE SVI-6. SYNTHETIC DIVERSION CURVES FOR LOW INCOME AREAS

Table SVI - 5

## TRIP UNIVERSES FOR TRIP DIVERSION ESTIMATES

Auto Trip Universe: 1975

Trip Purpose	Intra-P-J District	Intra-Low Income Area	Inter-Low Income Area	LIA to Sub-region (H-NW-H)	Total for ETRS	Totals for RCS	Totals for Other Services
H-W-H	10,676	17,226	16,756	67,804	44,658	67,804	
H-NW-H	19,994	22,512	22,420	54,430	119,356		
Other	54,626	60,028	27,415	547,826	142,069		547,826
Total	85,296	99,766	66,591	670,060	306,083	67,804	547,826

Transit Trip Universe: 1975

H-W-H	6,068	22,724	20,090	70,714	48,882	70,714	
H-NW-H	10,478	26,612	17,450	47,158	101,698		
Other	952	2,009	1,729	171,098	4,690		171,098
Total	17,498	51,345	39,269	288,970	155,270	70,714	171,098

Source: reference [T-16] Tables 6A-10, 6A-11.

round trips and made within a limited time period. Thus, all commuting trips between the subregion and the study area are excluded from the trip universe for this service. Except for Set IV, approximately 45% of the diverted trips are between home and work; 40% are between home and non-work; and only 15% of the trips are not home based. This particular pattern of demand arises because most trips are diverted from transit and because the area contains a much greater proportion of complete home-to-work trips than found in the CBD. This is especially relevant to travel between the study area and the CBD where there will be a very high peaking of demand which the MTS may be operationally unable to satisfy.

The complete 1960 and 1975 travel demand forecasts are shown in Figure SVI-7 for each set, value of time and for both marginal and total travel cost comparisons\*. The totals show considerable variation, but this is almost entirely due to the sensitivity of diversion from auto. In contrast, the number of trips diverted from transit show a remarkable stability. In Set I through III, only minimal trips are diverted from auto, whereas in Set IV, the position is completely reversed for both total and marginal cost comparisons. However, these new trips are also very sensitive to the value of time and experience a reduction as the value increased. The full impact of this is not apparent until the trips are subdivided by purpose. It is then clear that approximately 80% of the new trips are not home based and are therefore less likely to be made by local low income residents, but by local businessmen. This suggests that \$2.00 per hour may be the most appropriate time value to use to estimate demand in Set IV.

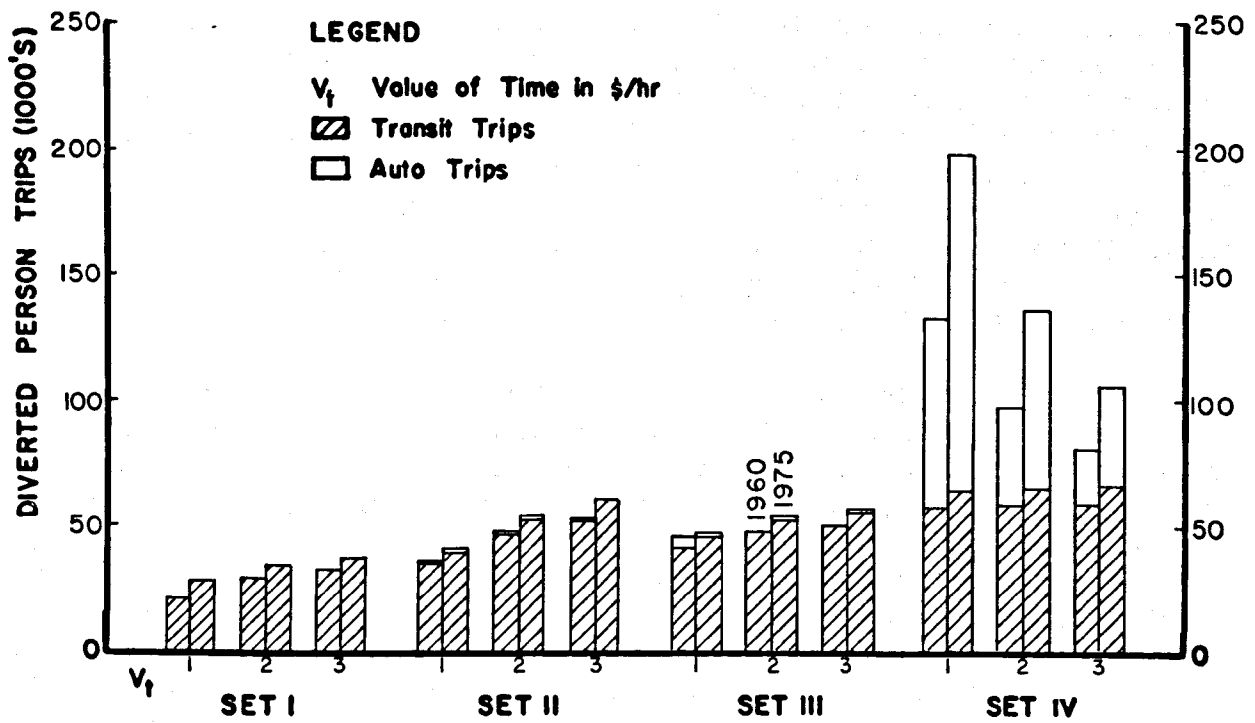
b. Reverse Commuting Service. This service caters only to the home-to-work trips originating in the low income areas and ending in the subregions. The estimated demand for this service is shown in Figure SVI-8 for each set, value of time, and for both total and marginal cost comparisons. Overall, the diversions from both auto and transit are proportionately higher for this service than for the extended trip-rate service, but they are also more sensitive to the value of time. In general, the higher a person values his time, the more likely he is to divert to the Minicar from transit, and the less likely from the auto. This suggests that unless the Minicar fare is similar to the auto cost per mile its use for reverse commuting might actually be very transitory. Persons could use the Minicar to find steady, well-paying employment in the suburbs and would then purchase their own auto for its added advantages.

One of the most critical factors in estimating the demand for this service concerns the value of time. The wage rates for most of the jobs associated with this service will be between \$2.00 and \$3.00 per hour.

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\* For actual numbers for these and subsequent estimates, see [T-16].

# 1960-1975 MARGINAL COSTS



# 1960-1975 TOTAL TRAVEL COSTS

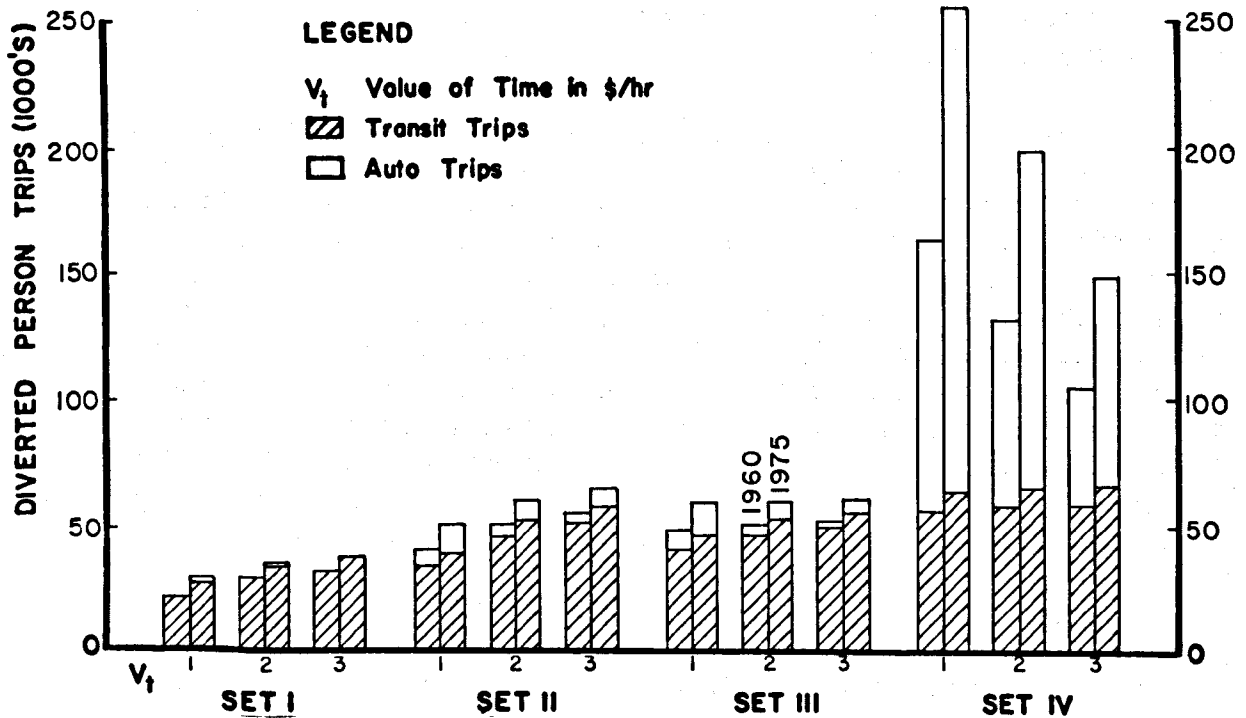


FIGURE SVI-7. EXTENDED TRIP RATE SERVICE DEMAND ESTIMATES

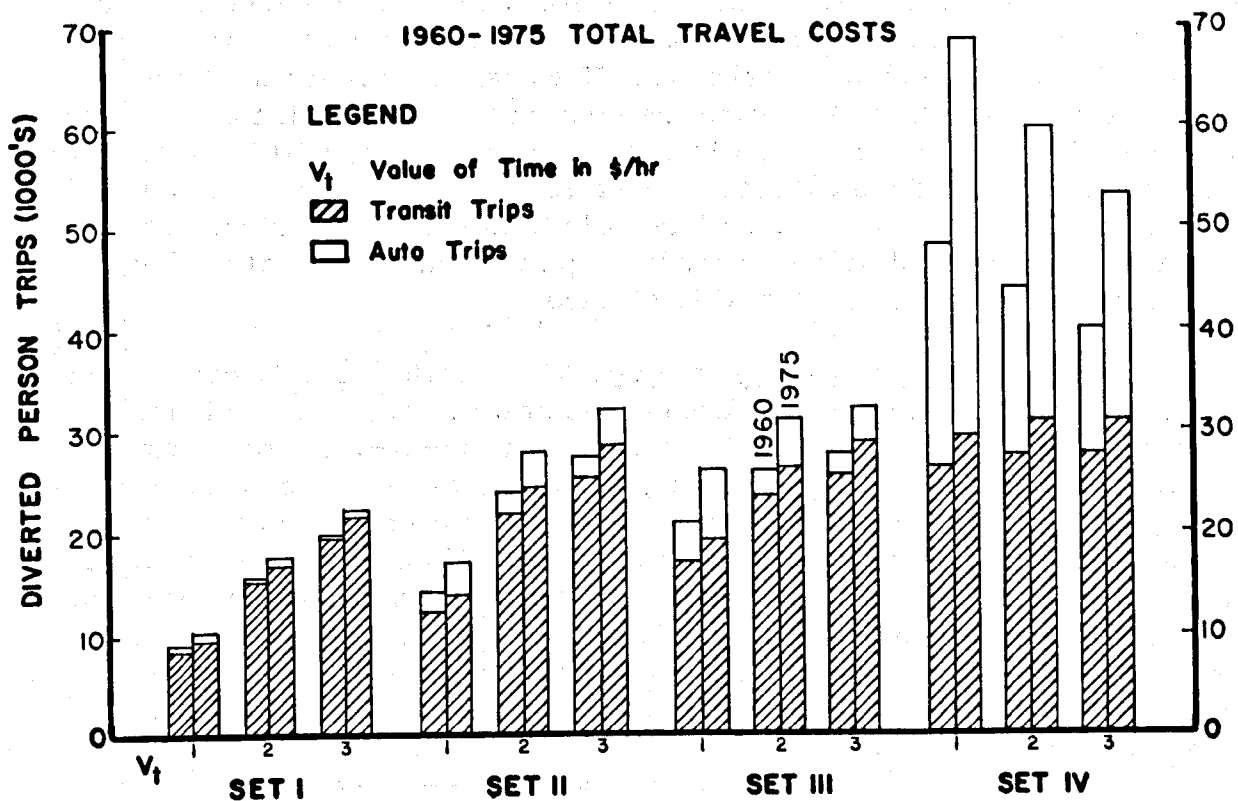
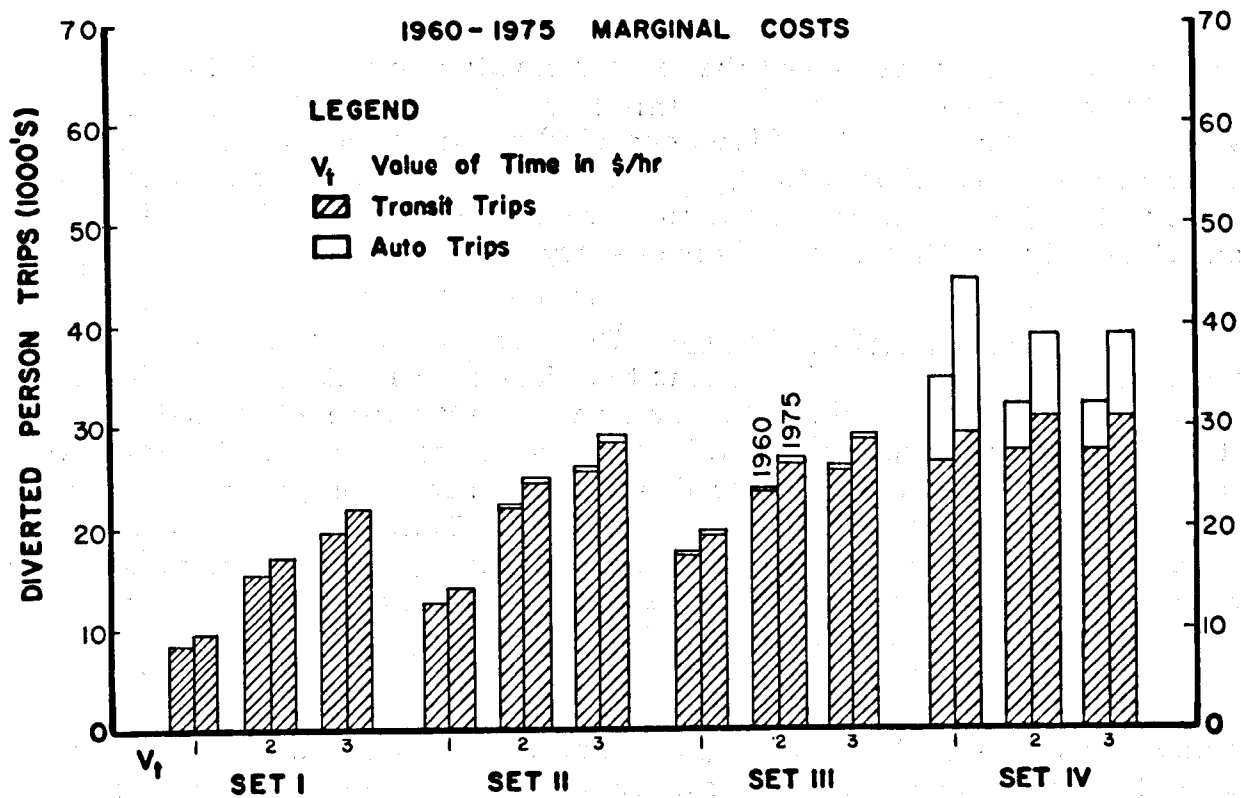


FIGURE SVI-8. REVERSE COMMUTING SERVICE DEMAND ESTIMATES



However, others have mentioned that a person values his time during his journey to work at a lower rate.\* If this is correct, it would mean that the lowest demand estimates ( $V_t = \$1.00$  per hour) might be the most probable ones to be realized. Thus if the total demand estimates for this service are critical to its successful operation, further work to determine the most appropriate value of time is clearly necessary.

c. Limited Trip-Rate Service. This service complements the reverse commuting service outlined above; it is therefore only available during evenings and weekends. It is intended both as a means of attracting additional revenue for the system and of providing a wide range of social benefits. The rationale for this service is that the full extended trip-rate service might not be implemented before the principal system is completed. During that time, the reverse commuting service could be implemented independently and require this more limited service either as its permanent complement or as a preliminary to the complete trip-rate system.

The demand estimates for this service are shown in Figures SVI-9 (Saturday) and SVI-10 (Sunday) for each set, value of time, day and for both total and marginal cost comparisons. Its overall demand characteristics are precisely the same as those described for the extended trip-rate service except that they are reduced in proportion to the total number of trips occurring during the evenings and weekends. However, manifest travel needs for this service, particularly during the evenings, is so small that steps to lower the effective fare rates to 10¢/mile/person or less, will be necessary if the service is to induce extensive diversion during these hours. Such changes should also be related very closely to any methods intended to stimulate latent demand since a very large part of this potential market exists during the time periods of this service.

d. Suburban Commuting Service. This service is only considered as part of the MTS in low income areas insofar as it can help or hinder operations there. Thus, it caters primarily to home-to-work trips from the subregion to the study area. However, as can be seen very clearly from the demand estimates for this service, most of the diversion is from transit, especially for the lower values of time. Its overall demand characteristics are very similar to those of the reverse commuting service, except that the auto operating costs for these persons are likely to be higher than for low income area residents. This would only affect the total travel cost estimates, increasing the diversions from auto in a manner equivalent to a 2-3¢ rise in the Minicar fare.

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\* This is the conclusion of W. G. Hansen from a number of regression analyses run by A. M. Voorhees and Associates, Inc., reported in [B-11].

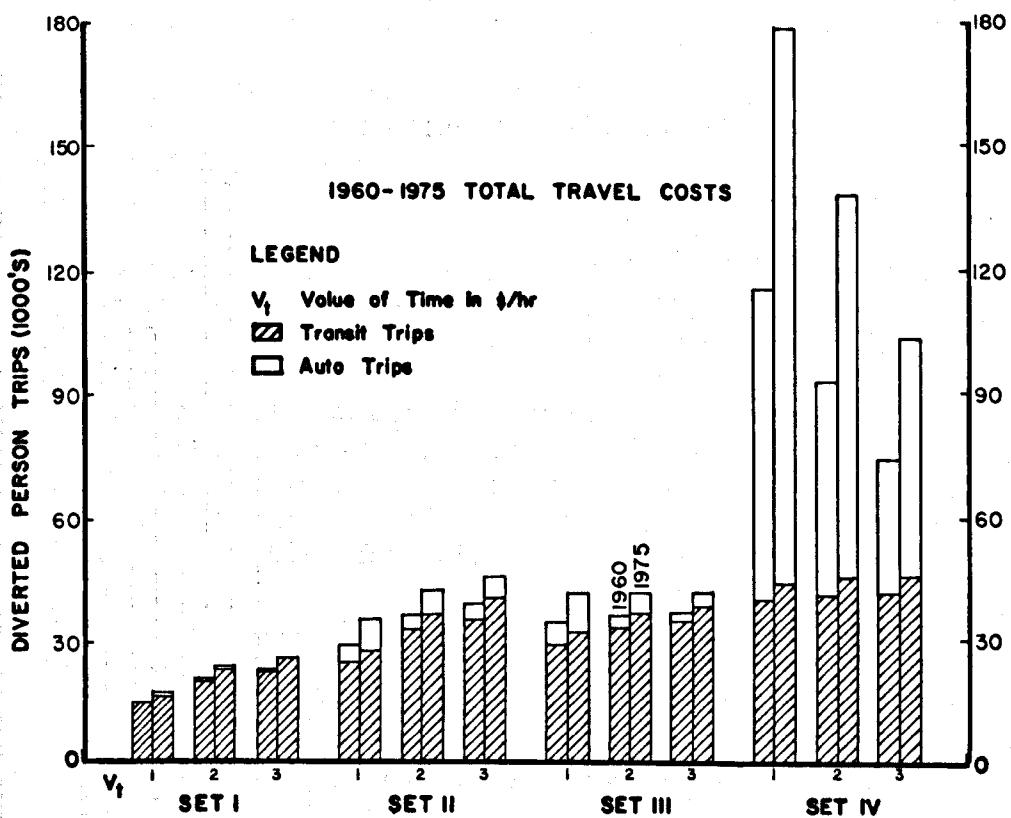
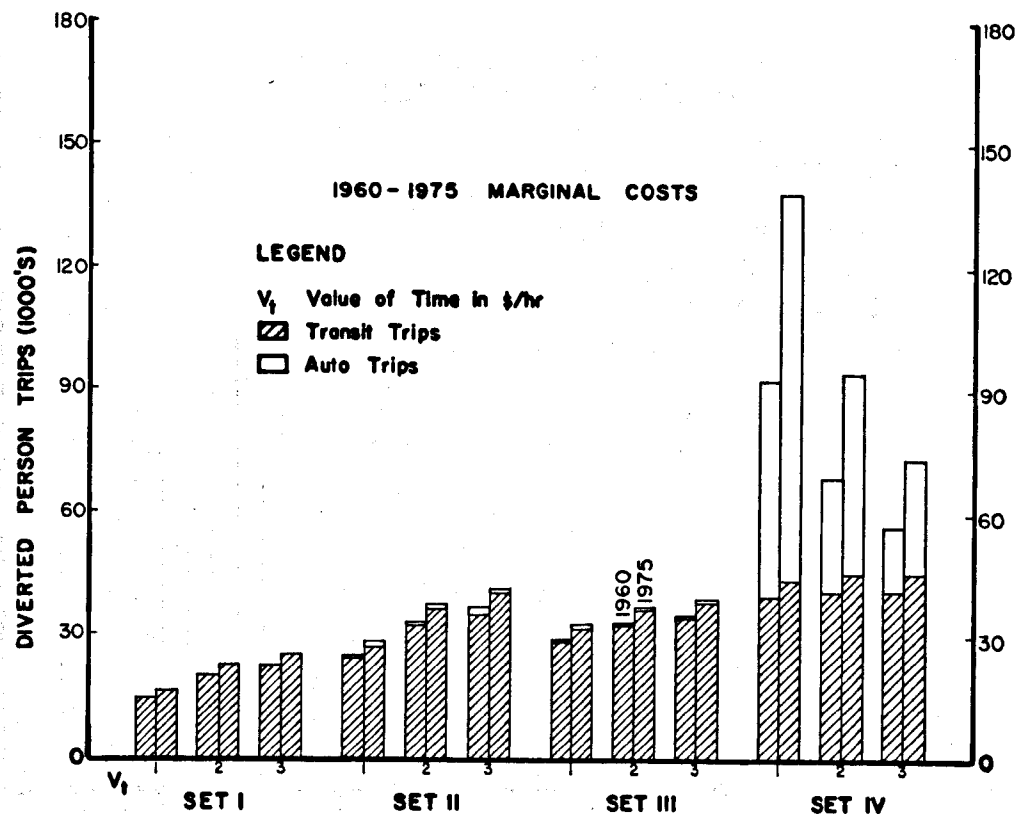


FIGURE SVI-9. LIMITED TRIP RATE SERVICE DEMAND ESTIMATES - SATURDAY

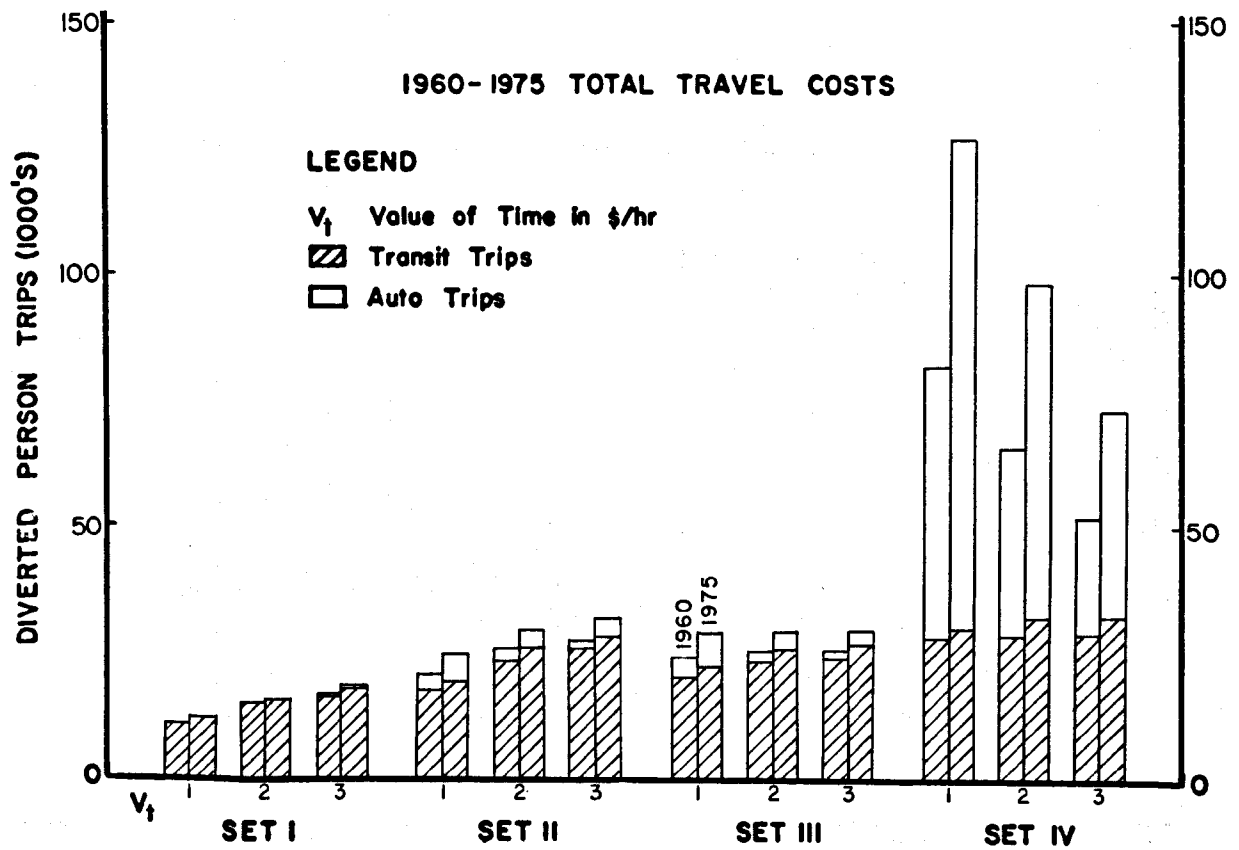
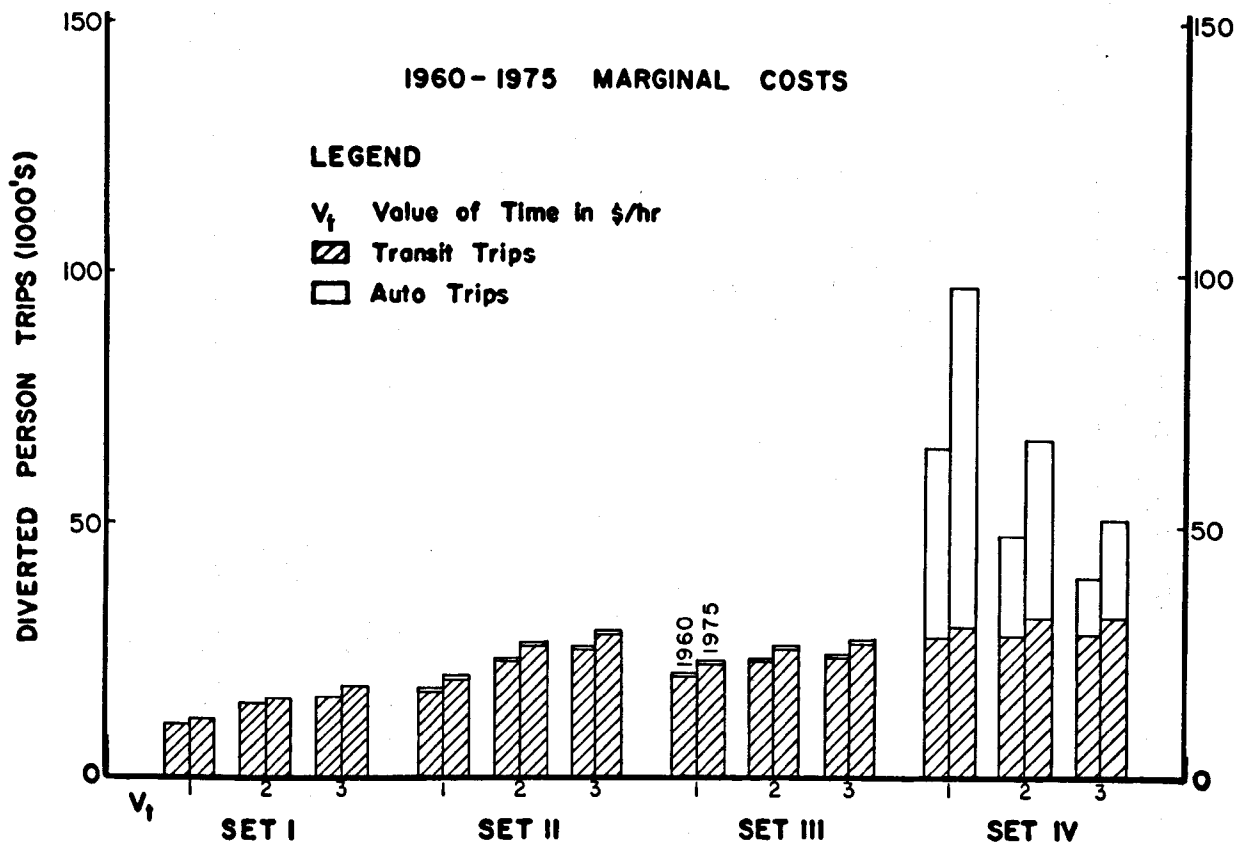


FIGURE SVI-10. LIMITED TRIP RATE SERVICE DEMAND ESTIMATES - SUNDAY

The major problem with this service is its enormous impact (25-35%) on transit travel between the low income areas and the subregion. Such diversions would undoubtedly increase traffic congestion very considerably and would most probably also result in a major reduction in the level of transit service between the ghetto and the region, thereby increasing its isolation. This is the exact reverse of both the goals of providing MTS service in low income areas and of the impact of this service on the CBD. This indicates the existence of some boundary, probably quite close to downtown, beyond which this service should not be offered if these negative effects on transit ridership are to be avoided. The present study area appears to be outside this boundary so that it is extremely doubtful whether the suburban commuting service should ever be introduced into Philadelphia's low income areas.

#### 6. Trip Estimates for Combined Services

At this point it would be very helpful if the essence of the various estimates can be stressed. Tables SVI-6 presents a summary of the projections of the three main services that appear both most reasonable and quantifiable: i.e. the "extended trip-rate service," ETRS, the "reverse commuter service" (RCS) and the "limited trip-rate service" (LTRS). Excluded are the "suburban commuter service" because of its clearly questionable social utility and the "suburban daytime service" which although very important and essential complement of the "reverse commuter service" cannot still be quantified enough to be reduced into specific numbers, at this time.

Table SVI-6 presents the total estimates of each of the three services under consideration for the middle value of \$2.0/hour and for all four sets of MTS cost ratio conditions, total auto travel cost and total transit travel cost.

What does this summary table indicate? First the ETRS demand clearly increases from set I to set IV for both 1960 and 1975 (from a minimum of 30,000 to a maximum of 197,000). Interestingly enough relatively small variations of diversion from transit were observed even with a stable value of time. The estimates of auto diversions show, however, a multiple increase from a mere 400 trips to a total of 132,800 (for set IV in 1975). Second, the reverse commuting service (RCS) estimates indicate smaller variation for both transit and auto diversions. The estimates indicate that for a fixed value of time the variation will be from 15,600 trips to 30,600.

The estimates of limited trip-rate service (LTRS) present variations as great as the ones registered in the ETRS, starting from only 50,800 trips to conclude with 325,700 trips. However, another particularity is part of these figures since the evening service will be available five times a week while the Saturday and Sunday service only once. To find the total weekly number of trips produced by the LTRS, one should multiply the evening service by five and then add the Saturday and Sunday trips. The equivalent daily trips would be found by dividing the total by five. These numbers are shown on the two last lines of the partial Table C of Table SVI-6. Again the variation is extended from 10,160 effective daily trips to 65,140 effective daily trips.

TABLE SVI-6. SUMMARIES OF DEMAND

(Value of time,  $V_t = \$2/\text{person-hour}$ )

Estimate Year	Source of Users	Cost Ratio Conditions (see p. 151)			
		SET I	SET II	SET III	SET IV
A. Daily Demand for Extended Trip-Rate Service					
1960	From Auto	400	4,400	4,000	74,600
	From Transit	<u>29,600</u>	<u>46,700</u>	<u>46,700</u>	<u>57,700</u>
	TOTAL	30,000	51,100	50,700	132,300
1975	From Auto	700	7,800	7,100	132,800
	From Transit	<u>32,800</u>	<u>52,000</u>	<u>52,000</u>	<u>64,200</u>
	TOTAL	33,500	59,800	59,100	197,000
B. Daily Demand for Reverse Commuter Service					
1960	From Auto	400	1,900	2,400	2,600
	From Transit	<u>15,200</u>	<u>22,000</u>	<u>22,000</u>	<u>23,400</u>
	TOTAL	15,600	23,900	24,400	26,000
1975	From Auto	800	3,300	4,000	4,500
	From Transit	<u>16,900</u>	<u>24,500</u>	<u>24,500</u>	<u>26,100</u>
	TOTAL	17,700	27,800	28,500	30,600
C. Weekly Demand for Limited Trip-Rate Service					
1960	From Auto	900	6,900	6,600	123,300
	From Transit	<u>49,900</u>	<u>77,000</u>	<u>77,100</u>	<u>95,200</u>
	TOTAL	50,800	83,900	83,700	218,500
	(Daily Equivalent)	(10, 160)	(16,780)	(16,740)	(43,700)
1975	From Auto	1,200	12,900	11,600	219,800
	From Transit	<u>55,200</u>	<u>85,700</u>	<u>85,800</u>	<u>105,900</u>
	TOTAL	56,400	98,600	97,400	325,700
	(Daily Equivalent)	(11,280)	(19,720)	(19,480)	(65,140)
D. Summary of Extended Trip-Rate Service and Reverse Commuter Service (Excluding Limited Trip-Rate Service, Suburban Commuter Service <u>plus</u> Suburban Daytime Service)					
1960	From Auto	800	6,300	6,400	77,200
	From Transit	<u>44,800</u>	<u>68,700</u>	<u>68,700</u>	<u>81,100</u>
	TOTAL	45,600	75,000	75,100	158,300
1975	From Auto	1,500	11,100	11,100	137,300
	From Transit	<u>49,700</u>	<u>76,500</u>	<u>76,500</u>	<u>90,300</u>
	TOTAL	51,200	87,600	87,600	227,600
E. Summary of Reverse Commuter Service (RCS) and Limited Trip-Rate Service (LTRS) (Excluding Extended Trip-Rate Service, Suburban Commuter Service <u>plus</u> Suburban Daytime Service)					
1960	RCS	15,600	23,900	24,400	26,000
	LTRS	<u>10,160</u>	<u>16,780</u>	<u>16,740</u>	<u>43,700</u>
	TOTAL	25,760	40,680	41,140	69,700
1975	RCS	17,700	27,800	28,500	30,600
	LTRS	<u>11,280</u>	<u>19,720</u>	<u>19,480</u>	<u>65,140</u>
	TOTAL	28,980	47,520	47,980	95,740

Two summaries are also presented in Table SVI-6. The first summary shows the combination of ETRS and that of the RCS. One can notice that without the daytime suburban service the system can attract an increasing number of trips, from 45,600 trips to 227,600 (for set IV in 1975). A sharp increase is also observed between set III and set IV that is due primarily to the increase of auto diverted trips (ostensibly in response to an increase of the parking charge from 10¢ to 25¢ per trip; and in response to the decrease of the distance between terminals from 2/3 to 1/3 of a mile).

The second summary presents the estimates of RCS and its complement, the LTRS. Again, the estimates indicate a growth of effective daily trips from 29,000 to 96,000 for 1975, and associates this growth with the increase of auto diverted trips between set III and set IV.

These trip estimates should then be utilized for further analysis of the system. They represent, of course, mid-points in terms of the value of time, and are the results of several restrictive assumptions with regard to the systems compared, but they can be considered as good indicators of a "conservative" expectation of trips for a MTS in low income areas. Again, it is important to recall that (a) the set of circumstances assumed were devoid of any special measure or action in favor of the Minicar System, (b) the estimates include only diversion from actual (manifest) trips that for low income areas represent only a small percent of total travel demand of average households (i.e. no estimate of latent travel demand is included), (c) the estimates do not include daytime suburban service that is a natural complement of the reverse commuting service, nor do they include any other special use of vehicles during their idle hours (post office use, parcel delivery use, etc.) and (d) to some extent the limited trip-rate service should be more of a type complementary to the extended trip-rate service, rather than replacement of it (i.e. trips during the evening hours and during holidays are only partially included in the universe of the extended trip-rate service).

## 7. Latent Travel Demand Estimates

Latent demand has been defined in various ways. Some persons regard it as potential demand minus actual demand; others prefer to consider it as demand not now exercised but which could be at any time; and still others define it as demand which is not currently exercised because of defects in the transportation services available, but which will be exhibited as soon as the defects are remedied. None of these are particularly well suited to the needs of the Minicar Transit System, so that for the purpose of this study, latent demand is defined as:

"That demand which may arise due to the presence of special qualities of the MTS and which may not be attributed to any substitution from other modes."

This is both a strict yet broad enough definition. In particular, it includes the trip that is not yet considered, and the demand that might be realized because of the indirect improvements that may result in the transportation system. The first category would include demand generation following a pattern similar to the experiences of the xerox machines and the long-distance telephones. The second category is more complex and needs to be considered from a number of different viewpoints. The ability of the MTS to improve the transportation system in low income areas is comparatively limited to judge from the number of unfavorable cost ratios shown in Figures SVI-5. The ability of the system to serve low-skilled or handicapped persons is virtually nil because of the need to drive. In addition, other types of latent demand may exist but not be realizable. For example, neither the xerox machine nor the long-distance telephone have been widely adopted in low income areas many years after their innovation. Nor is there any evidence anywhere that a transportation innovation has ever been adopted first by low income persons. Even in under-developed countries, the extensive use of change-agents has had only marginal effects on this general pattern\*. An argument in support of the existence of latent demand for the Minicar is that since trip generation always rises as auto ownership increases, the added availability of the Minicar will automatically result in higher trip generation rates and latent demand for the Minicar. However, this is a rather complex argument because increases in auto ownership and trip generation rates are usually associated with rises in income which pay for the extra trips. Only if the introduction of the MTS is followed by relative changes in income, can it then be argued that the added availability of autos will result in an increased ability to pay for the additional trips and therefore produce realizable latent demand.

There are two very critical factors which influence the realization of latent demand for the MTS in low income areas. These are its fare structure and its rate of diffusion. The sensitivity analysis indicated an extreme sensitivity to the Minicar fare for manifest travel demand and there is no reason for latent demand to be any different (see [T-15f, 2(b)]). The rate of diffusion is discussed elsewhere and it is likely to be slow for all but the relatively high income persons living in low income areas (see [T-16g, 3, footnote 7]). The socio-economic groups likely to be most receptive to the system are young persons and middle income households. However, these groups are already the most auto oriented in the study area, so that their adoption of the system may be limited by the less than favorable Minicar/auto cost ratios (see [T-16a, Figure 1.14]).

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\* Change-agents refer to local administrators, community leaders, etc. who are specially commissioned to speed adoption of the innovation.

One of the clearest conclusions that can be drawn from analyzing travel characteristics and expenditure patterns in low income areas is that the limited travel demand of low income persons is due to both their depressed economic status and deficiencies in the transportation system. \* For example, high income persons living in low income areas make considerably greater use of transit facilities than do low income persons; the same high income persons make only 20% fewer trips than high income persons living in suburban areas which is considerably less than would be expected from the differences in living styles [T-15c, Figure 1.8]. Low income families often spend less than \$300/annum on transportation compared to over \$1,000 for households with incomes of more than \$10,000. Moreover, low income households spend a lower proportion of their income on transportation than higher income groups, indicating that shelter and food are necessities which have higher priorities [T-15c, Figure 3.7]. Thus, unless the Minicar is made considerably cheaper, and/or the incomes in those areas increase, latent demand in low income areas will be minimal. The corollary is that latent demand in low income areas can be stimulated to the extent that one is prepared to subsidize it.

On the basis of these thoughts one can proceed suggesting several estimates that can produce a "guestimate" of latent demand for an MTS in low income areas. These trips will be, of course, in addition to the diversions that have been estimated from manifest travel demand and would be highly fluctuating and always subject to the realization of the two conditions set i.e. improvement of the overall transportation service in low income areas and increase of incomes in those areas. Essentially, then, the suggested estimates are based on the differences in travel demand between the residents of low income areas and residents of other areas with better transportation services and incomes similar to the ones the low income area residents will have in 1975 with the introduction of the Minicar. They are also based on the estimated diversion rates of trips to an MTS among the various types of manifest travel demand.

The first step in these calculations is to observe that, in Philadelphia in 1960, a modest increase in income from \$3900 to 5800 (areas A and D in our comparisons- see [T-15a]) corresponds to an increase in the daily average number of total trips generated per person from 0.49 to 0.79, even where severe reduction of transit services is observed. Accordingly, one can postulate that if the introduction of a complete MTS in low income areas (and several incremental improvements can occur in these areas) be instrumental in increasing the incomes in these areas by 40% there would be a corresponding increase of person trips approximately equal to 60% of present trips. Most of these trips will be non-work trips and off peak trips.

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\* Travel characteristics are examined in reference [T-15a] and travel expenditures in reference [T-15c].



The analysis of potential diversions from manifest travel demand of trips directly related to the home origin in low income areas has utilized as "trip universe" approximately 460,000 (306,000 extended trip-rate service and 155,000 reverse commuter service). From these trips the diversion analysis indicated that between 1/6 and 1/2 would probably divert to the MTS. If similar influences affect latent demand trips, one can reasonably accept that similar diversion averages will be experienced in 37,700 and 95,675 additional trips will be added to the Minicar total, due to additional trips (beyond and above those expected otherwise) that will be generated in low income areas if a complete MTS is established and personal incomes increase by 40% above 1960 levels.

## 8. Other Demand Estimates

The manifest demand estimates specifically exclude any diversion from non-home based auto and transit trips between the LIA and the rest of the region, corresponding to 547,000 and 171,000 trips for 1975.\*\* In addition, the improvement of the transportation conditions and income levels within the low income areas due to the establishment of a complete Minicar System can reasonably be expected to induce additional non-residential activities in these areas (offices, business special "clean" plants, etc.). It is reasonable also to assume that trips made to and from these activities from areas with Minicar facilities (i.e. the CBD of the region) will tend to use, in some proportion, Minicars. On this basis, a generalized estimate of Minicar trips is added to the previous estimates. (These trips will, of course, tend to improve the financial feasibility of the entire MTS, but they would have little impact on the travel needs of LIA residents, themselves.) Since the detailed data that will assist in a detailed determination of potential Minicar diversions from this additional trip universe are completely lacking, the estimates that are made are based on the calculated overall proportions of diversion that the manifest trip estimates have produced. In this case, the most adverse overall proportions, found earlier, are being utilized as "suitable conservative" measures. Also, the "unadjusted" trip universes for 1975 are used. Thus, one may calculate, using the same diversion rates as the other trip universes:

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\* The calculations are as follows:

	Set I	Set IV
306,000 (ETRS trips) x 0.60 (increase) x 1/6 diversion	30,600	
306,000 (ETRS trips) x 0.60 (increase) x 1/2 diversion		91,800
155,000 (RCS trips) x 0.10 (increase) x 1/5 diversion	3,100	
155,000 (RCS trips) x 0.10 (increase) x 1/4 diversion		<u>3,875</u>
Totals	33,700	95,675

\*\* See Table SVI-5 and Appendix Table 6A-11 of [T-16] and compare Tables 6-4 and 6-5 of [T-15e].

$$547,000 \times 45\% \times 1/12 = 20,512$$

$$171,000 \times 75\% \times 1/10 = \underline{12,825}$$

33,337 non-home based Minicar trips for  
Sets I and II

and  $547,000 \times 45\% \times 1/10 = 24,615$

$$171,000 \times 75\% \times 1/8 = \underline{16,031}$$

40,646 non-home based Minicar trips for  
Sets III and IV.

#### 9. Summary of All Estimates

On the basis of all previous estimates a summary may be formed of the average numbers of trips produced utilizing \$2.00/hour/person, for 1975, i.e.

<u>Service</u>	<u>Set I</u>	<u>Set II</u>	<u>Set III</u>	<u>Set IV</u>
ETRS	33,500	59,500	59,000	197,000
RCS	17,500	27,500	24,500	30,500
L. Demand	33,700	33,700	95,675	95,675
N.H. Based	<u>33,337</u>	<u>33,337</u>	<u>40,646</u>	<u>40,646</u>
Totals	118,037	154,037	219,821	363,821

These totals indicate a "reasonable range" of Minicar trips that an MTS for low income areas in Philadelphia may expect to attract in 1975, if MTS is (a) open to all, (b) provides services within and about the low income areas and (c) includes reverse commuting and daytime suburban service.

## E. Sensitivity of Manifest Travel Demand

### 1. Introduction

Demand for the MTS is dependent upon a large number of endogenous and exogenous variables. Some of these were included in the four sets of operating conditions used to prepare the preceding demand estimates. However, these are not sufficient to indicate the effect of each variable on the system's optimality and for that reason a preliminary sensitivity analysis was attempted, based primarily on what was found in analysing potential diversions from the manifest demand sector (See also [T-15f]). The travel demand is considered dependent upon five major variables. These are:

Minicar Fare Structure	)	Endogeneous
Terminal Spacing	)	Variables
Value of Time	)	Exogeneous
Auto Parking Cost	)	Variables
Total and Marginal Auto Operating Costs)		

Their effects on two trip universes are examined: trips entirely within the study area, and trips to the subregion. This is undertaken because the differences in the trip lengths sometimes induce quite different responses.

### 2. Sensitivity of Travel Demand to the Minicar Fare Structure

Travel demand for the Minicar within low income areas is very responsive to changes in the fare structure, especially when total travel costs are compared.\* Persons with low values of time are particularly responsive because for them, the out-of-pocket cost is a much greater portion of their travel cost. This is most noticeable for trips diverted from auto. Overall, the responses to changes in the fare result in about a 50% overall loss of demand as the fare moves from 5¢ to 30¢ per person per mile.

Travel demand to the subregion is considerably more sensitive although it exhibits the same overall characteristics as travel within the low income areas. This greater sensitivity can be attributed to two factors. First, the trips are now longer so that the approach and destination costs are proportionately less important, and second, faster travel speeds reduce the time costs but leave the fare costs unchanged. There is also a greater difference between the total and the marginal travel demand estimates for trips

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\*For graphical representations and further details, [T-15f, 2(b)].

to the subregion than within low income areas. This is wholly due to the sensitivity of the diversion from auto when the Minicar fare is between 5 and 10¢/person/mile.

### 3. Sensitivity of Travel Demand to the Value of Time

Overall, travel demand within the low income areas appears surprisingly insensitive to variations in the value of time. [T-15f, 2(c)] This is because of the very high proportion of trips consistently diverted from transit. This stability does not carry over to the diversions from auto. These diversions are sensitive to the value of time and clearly indicate that the more an individual values his time the less likely he is to divert from his auto to the Minicar. Trips to the subregion respond in a similar manner with more pronounced difference in response between transit and auto diversions.

### 4. Sensitivity of Travel Demand to Terminal Spacing

The changes in travel demand resulting from different terminal spacings are surprisingly small for all classes of trips. [T-15 f, 2(d)] Those who value their time highly appear more prepared to walk than those who do not. This is because the majority of diversion is from transit and these persons can save considerably by using the Minicar. As would be expected, this behavior is not characteristic of present auto users; these persons very quickly reject the Minicar as the terminal spacing increases.

### 5. Sensitivity of Travel Demand to Auto Parking Costs

The overall effects of this cost are small, especially for trips to the subregion. [T-15 f, 2(e)] The reason for this is that only a small proportion of this travel demand, specifically that diverted from auto, is affected by this cost. Where this is not so, auto parking cost, especially for persons with a low value of time, could exert a considerable influence over the travel demand for the Minicar on short trips.

### 6. Sensitivity of Travel Demand to Diffusion of an Innovation

Travel demand analyses which concentrate upon modal characteristics necessarily ignore many of the social and psychological factors which influence an individual's selection of one mode over another. This omission becomes critical when an innovative system is introduced since its diffusion through the social system usually takes time. This issue is particularly critical to the demand estimates because the method of forecasting employed here assumes a high degree of awareness. Thus, the demand estimates are predicated on the assumption that soon after the system's introduction the vast majority of residents of low income areas will

become aware of the presence of the system, its working details and its potential benefits to each one of them. This is a particularly important point and assumes, in turn, an aggressive management, fully developed public support and good advertizing campaigns.

#### F. System Feasibility in Low Income Areas

The analysis of the feasibility of the three services under consideration, (i.e. the Extended services, Extended Trip-Rate, Reverse Commuting, and Limited Trip-Rate) was primarily economic and sought to determine the average daily mileage per Minicar needed for financial viability. This mileage was computed for different vehicle costs, fare structures and paying person occupancy rates. It was then compared to the empirical average trip lengths\* and the travel demand estimates, assuming different numbers of trips per Minicar per day to indicate which sets of operation conditions are feasible, indeterminate, or infeasible. For the Extended Trip-Rate Service, the analysis indicated the following break-even points, given in number of daily trips per car; car occupancy of one, no terminal charge; and no time charge for the vehicle.

##### Number of Trips Per Car Required for Breaking-Even under Various Conditions

Daily Cost per Minicar	\$3	\$4	\$5
Fare: 10¢/mile	10	12	15
Fare: 15¢/mile	6	8	10
Fare: 20¢/mile	5	5	7

An examination of the temporal distribution of demand throughout the day indicates that a Minicar should reasonably expect to experience 10 to 16 trips per vehicle per day.

Under the same limiting conditions the analysis indicated that the Reverse Commuting Service is clearly feasible provided that \$2.00 per day per Minicar can be produced from either suburban use or evening use of each vehicle. In a combined system of ETRS, RCS, LTRS and Daytime Suburban services these requirements can be met most probably without much difficulty. Given a subsidy of \$1/day/vehicle, the fares could be reduced to 15¢ per mile for paying person occupancy rates of 1.0.

The Limited Rate Service is feasible provided that the cost of terminals in low income areas can be kept below \$1.00 per vehicle per day.

#### G. Impacts of an MTS in a Low Income Area

This study examined the MTS as a potential contributor to social and economic advancement in urban low income areas. The impact of each service was examined separately. The potential social and economic advancement has been examined as a function of four independent variables: physical mobility, skills, individual motivation and real opportunities. Each of these is

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\* See [T-16, Tables 1A-13, to 15; 6A-1A to D; and 6A-4A to D].

considered as a necessary but insufficient condition for actual advancement. Only their concurrence can insure major changes in low income areas.

The impact of the Extended Trip-Rate Service is examined for a 20¢/mile fare and terminal spacing of 1/3 mile. Diversion rates of manifest travel demand under these conditions are 30% from transit and 2% from auto. The overall impact of such diversion on employment should be expected to be very small although particular groups of individuals would, of course, benefit. Many more persons would benefit, however, from improved shopping and recreational facilities. There would be no significant impact on housing patterns. Latent travel demand will tend to increase the impact of the MTS on all these aspects of urban life.

The Reverse Commuting Service would tend to produce a relatively small but quite important impact on work opportunities for the residents of low income areas. In general 10,000 to 15,000 job seekers will be able to benefit from this service. However the service should be closely linked to existing job training programs so that subscribers are highly motivated and partially skilled.

The Limited Trip-Rate Service has the greatest potential for both social benefits and attracting latent travel demand for the MTS.

#### H. Summary and Conclusions

The main purpose of this part of the study, reported in this chapter, was to examine the possibility and desirability of extending an MTS (that already would have been established in the CBD of the region) into the low income areas of the central city. In examining this problem the Philadelphia SMSA was used as a case in point. The area examined envelops the central Business District of the City of Philadelphia on three sides. In 1960 it contained 54,000 persons with a median household income of \$3,792. This compares with two million people and \$5,927 median annual household income for the city of Philadelphia in general.

The Minicar services that were examined and found potentially suitable or appropriate for the low income areas were the following:

(i) Extended Trip-Rate Service, that is quite similar to the Trip-Rate Service that would be available in the CBD area, and permits trip interchanges within the low income areas and between low income areas and their immediate vicinity.

(ii) Reverse Commuting Service, a trip-rate service or flat rate service (per month, week, day) that is intended to enable residents of the low income areas to reach job opportunities in the inner suburbs. This can be an independent service or a complement of the Extended Trip-Rate Service.

(iii) Limited trip-rate service, that is intended to make Minicars available during evening hours and on week-ends on trip-rate basis or flat rate basis. This service is examined as an independent service or as a complement to the Reverse Commuting Service and/or complement to the Extended Trip-Rate Service.

(iv) Suburban Daytime Service, that is intended to utilize the Minicars of the Reverse Commuting Service, during the hours 10:00 am - 4:00 pm for commercial, business, recreational trips by suburbanites and/or workers.

The analysis of the economic feasibility of the various services indicate that their feasibility would depend on several items. First it would be advisable to establish adjustable fare rates. The System could also include a variable entry and exit charge over terminal plus a mileage and time charge. For instance a trip from a low income area terminal to one of the downtown terminals could be charged as follows.

Exit LIA Terminal	10¢
Entry CBD Terminal	15
2 miles at 5¢ per mile	10
16 minutes at 1/2¢ per min.	<u>8</u>
Total cost of the one-way trip	43¢

Terminal charges could be varied by time of the day or terminal location. Also public subsidy can be introduced to the System, in setting terminal charges, if agreed upon, for low income areas. Another particularity which an MTS for low income areas might have is a shared-trip-rate-cost option, that would permit reduction of cost to the individual user.

In terms of the support that each type of service would attract, the Extended Trip-Rate Service would tend to attract the largest number of trips but a significant proportion of these trips will be from present transit trips to and from the low income areas (primarily because of the limited number of auto trips at present in these areas). The MTS can become financially feasible for Extended Trip-Rate Services under the circumstances and fare structure outlined in Section F of this chapter.

The analysis of demand throughout the day indicates that the service should be able to achieve 10 to 16 trips/day/car. More trips can also be made if additional services are available and a system of MTS terminals are established in many parts of the region. In overall terms, the significance of this service alone will be primarily in providing service for existing and new shopping, personal services, and recreation-trips. Only a small impact on employment opportunities can be expected.

The Reverse Commuting Service would be able to complement the picture by providing the means for commuting by Minicar to the inner suburbs for work purposes. The demand for this service is particularly sensitive to the value that the traveller places on his time. This service also has a significant potential for satisfying an important part of the latent travel demand of low income area residents for new work trips. The limiting factors for this type of service would be the number of potential workers who are not licensed drivers, and availability and location of jobs in suburban areas. Both are partial obstacles which can be overcome to a large extent by proper measures. The Reverse Commuting Service would definitely need additional financial support if operating alone; in conjunction with the Extended-Trip-Rate Service and the Suburban Daytime Service it can become financially feasible.

The third complementary service, the Limited Trip-Rate Service, would also be effective in attracting trips and would be the most successful single service for satisfying latent demand (daily after 5:00 pm and on weekends) especially if the Minicars could be rented by the hour with only a small supplementary mileage charge. Again, this service can become financially feasible even when provided alone if the cost of operating the terminals in low income areas can be kept below \$1.00 per vehicle per day. In conjunction with other services this cost level becomes easily achievable. In terms of overall impact this service should be expected to have an impact similar to the impact of the Extended Trip-Rate Service, for work, shopping, personal services, and recreation trips in low income areas.

The final complementary service that fits in the overall picture is the Suburban Daytime Service. This service would be rather irrelevant for the needs of the low income area resident, but this service may assist materially in covering the cost of other services, particularly the Reverse Commuting Service. An independent service of this type does not really make sense and would tend to be a deficit operation; in association, however, with the other services it would tend to provide needed services for suburbanites and workers in suburban areas and at the same time alleviate the financial burden of the other services.

A preliminary analysis of the possibilities that latent travel demand in the L.I.A. may include for an MTS system indicates that a reasonable diversion from this source would vary from 33,000 to 96,000 daily trips. To this one should add the potential diversion to MTS from non-home based trips, i.e. trips made to and from the multiplicity of businesses that are located in low income areas. The expectations from these sources vary from 33,337 to 40,646 daily trips.

A preliminary sensitivity analysis of the System's demand expectations to five effective variables (fares, terminal spacing, value of time,



parking costs, auto costs) indicates that there is considerable sensitivity of the demand estimates to these variables. This sensitivity can be used to maximize the systems support and maximize the social and economic benefits from the System. Also this sensitivity can produce major obstacles to the welfare of the System if not taken properly into account in planning.

The final conclusion, and the major finding of this study, is that a widely supported MTS for low income areas can be built including the following characteristics.

(a) A system of terminals approximately 1/3 miles apart within the low income areas that provide for:

(i) Flat and Trip-Rate Services within and around the low income areas during the weekdays;

(ii) Reverse Commuting Services from the low income areas to a set of selected suburban districts appropriately located and including appropriate job concentration; and

(iii) Evening and weekend services within and around the low income areas.

(b) A system of terminals in a number of suburban areas (approximately a dozen appear probable at this time) that are located within a distance of less than 12 miles from the Philadelphia CBD and that include important concentrations of jobs suitable to the skill levels of low income (unskilled or semiskilled) individuals. This set of terminals will provide the following services:

(i) Discharge and pick-up services for vehicles used for the Reverse Commuting Service of low income areas; and

(ii) Daytime (10:00 am to 4:00 pm) suburban services for suburban housewives and others primarily for shopping, recreation, medical and school trips.

Firm economic feasibility of such a System cannot be determined at this point without sufficient information on the cost of setting up and operating such a System, especially when it has become apparent in the process that such costs can vary widely. Thus a parametric analysis is presented that indicates the conditions that must be met in order for the system to become feasible.

In terms of managerial form it appears that no single form is particularly suited to all types of services. In fact, a composite managerial set-up seems to be the most promising. In all cases the management should be quite aggressive in selling its product and should use modern techniques in marketing with creativity, ingenuity and persistence. Under those circumstances, a private firm could provide all types of services except the Reverse Commuting Service. This type of service, because of its potential impact on employment and the probable desire to strengthen it with public support (subsidy), can be set up under a special managerial unit, as a non-profit organization. In such an arrangement, the public, non-profit organization can lease its Minicars and the other associated facilities of the system from the major private firm that would provide the MTS in the region.

## Technical Supplement S-VII

### ECONOMIC ASPECTS

This Supplement summarizes the research performed to estimate the economic aspects and feasibility of a Minicar Transit System. More specifically, the objective of this research was to assess the profitability, capital requirements, growth rates, and initial investment necessary to maximize the probability of financial success for the MTS.

Prediction of these economic aspects of the MTS is difficult not only because all costs must be projected into the future, but also because some of the basic aspects of the organization of such a system which may affect its economics (such as the nature of the operating authority and the amount of taxes, if any) are not certain at the present time.

Due to this complexity and changes in the concept of the MTS during this project a numerical analysis of financial aspects of MTS has a limited value. Consequently, it is considered that the most significant contribution of this research is the development of a computerized financial simulation model of the System which permits introduction of a number of assumptions as well as any numerical values for individual items. The model can therefore be used at any stage of planning and evaluation of the MTS. In particular, it enables more effective planning for experimental installation of MTS's, and ensures a more complete utilization of data from such experimental installation. It is also possible to test the impact of any changes in assumptions or numerical values on the economic aspects of the System.

The model will be briefly described here. Then, the estimates of costs and revenues, which will be consequently introduced into the model, will be presented. Financial feasibility of the System as well as its sensitivity to the revenue and cost assumptions are analyzed.

The primary achievements of this second year of economic analysis are the sensitivity analysis and the extension of the financial model to a more sophisticated form. However, for the convenience of the reader, many of the cost and revenue assumptions which were retained from the first year's work are duplicated here.

The cost and revenue estimates which follow represent the best estimates made by the various research groups on the Project during 1968. Since some of the numerical estimates were developed in the course of the research and documented in internal memoranda only, not all sources are quoted in this text.

### A. The Model

Economic feasibility of the MTS was analyzed with the aid of computer simulation. A model of the cash flow and income statements was designed to handle projections up to 48 quarters into the future. The purposes of such a model were:

1. To provide a tool for rapid recalculation of income projections as cost and revenue assumptions were changed.
2. To allow sensitivity analysis to be performed to cost and revenue assumptions.
3. To search for profit maximization points in terms of optimal system size.
4. To allow efficient financial evaluation of operating system performance during the experimental stage.

The flow diagram in Figure SVII-1 gives a simplified picture of the operations of the model. There are essentially three main operations involved.

1. Calculation of net income and cash flow to give present-discounted-value (hereafter referred to as PDV).
2. Variation of the maximum system size (in terms of the number of cars) .
3. Variation of the rate of introduction of Minicars.

Net income and cash flow are calculated for each quarter of a MTS System which has as given a rate of vehicle introduction and a maximum number of cars. After the cash flow and income figures have been generated for 48 quarters, they are discounted at 10%/year. Iterations are performed with the maximum system size ranging between 2,000 and 14,000 cars (in steps of 2,000) and the rate of introduction ranging between 225 cars per quarter and 1625 cars per quarter (in steps of 200). The result is a three dimensional set of figures which have been graphed in order to discover the PDV-rate-size combination which will maximize PDV. The graphs are presented later in this Supplement (Figures SVII-5 and 6).

A basic cash flow statement is generated from a set of cost and revenue assumptions, a given rate of introduction of vehicles, and a given system size. Looking at the flow diagram (Figure SVII-1) this would be equivalent to stopping at decision block 4. No iterations on system size or rate of introduction are performed.

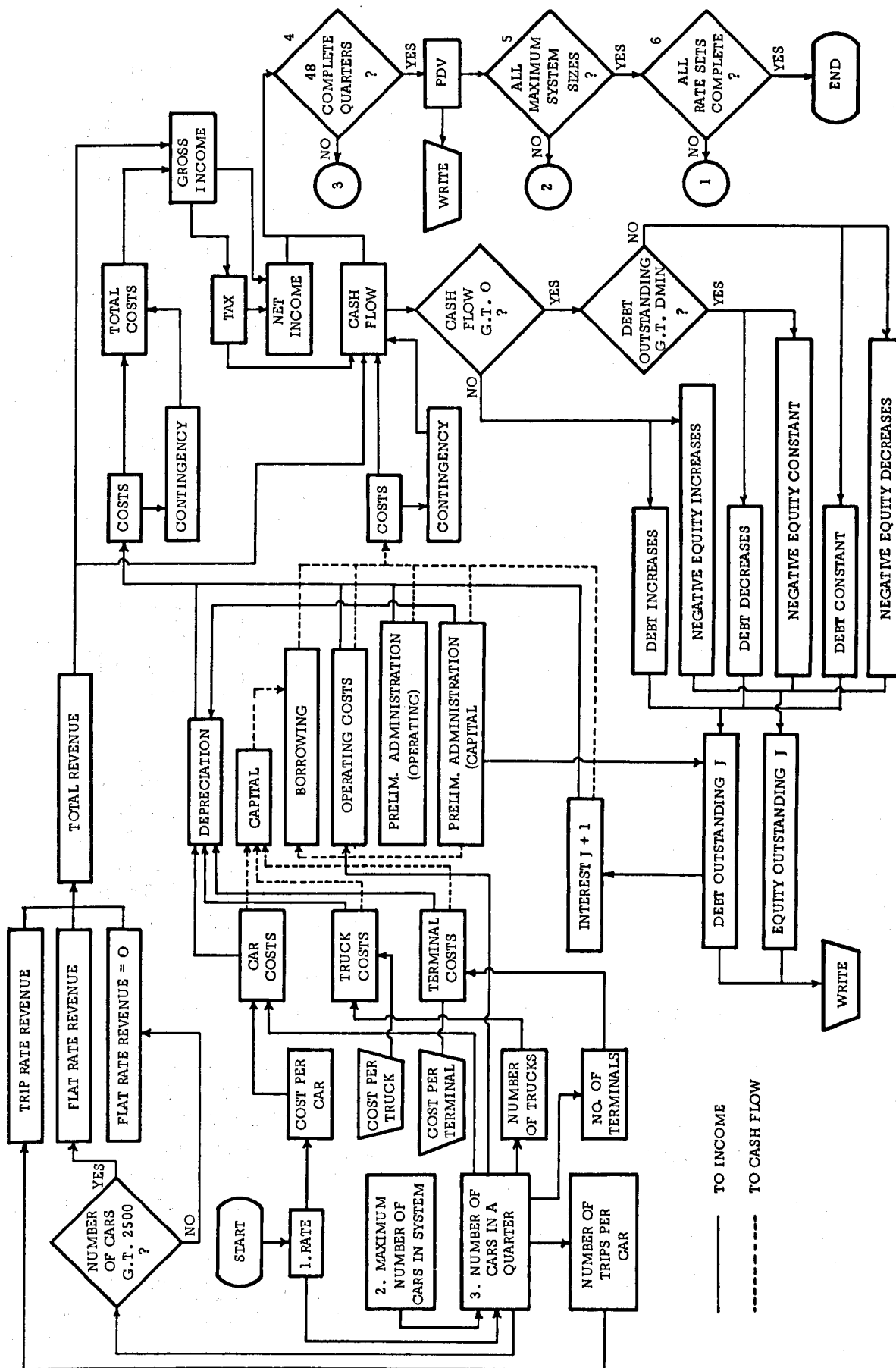


FIGURE SVII-1. FLOW DIAGRAM OF THE OPTIMIZATION MODEL

The next six paragraphs give a detailed explanation of cash flow and net income calculations. Unit cost per Minicar is determined on the basis of the rate of their introduction. The cost per maintenance truck and cost per terminal are assumed. Each quarter, more cars, trucks and terminals are purchased until the maximum system size (in terms of number of cars) is attained. The number of cars in a given quarter is therefore determined by the rate of introduction, the maximum system size, and of course, which quarter it is. The number of cars, in turn, determines the number of trips per car, the number of trucks, the number of terminals, and operating costs. Operating costs consist of the following items: direct operating expense on the vehicle, washing, insurance, parking, license/title fees, personnel, overhead, and information system operating costs.

Trip rate revenue is computed from the number of cars that quarter, the number of trips per car, and the trip rate. The flat rate option is initiated after the System size exceeds 2,500 cars with one flat rate trip allocated to each car in excess of 2,500. Trip rate plus flat rate revenue determines total revenue.

Net income is determined by adding operating costs, depreciation expense, preliminary administration operating expense, and interest expense. A 10% contingency is calculated on the sum of these costs and added to them. The result is total cost which when subtracted from total revenue gives gross income.

It is important to point out that the program must compute an income statement for a given quarter before it can calculate cash flow. This is because federal income taxes are needed to determine cash flow. Both the net income and cash flow results were used to calculate PDV in order to check them for consistency. The results were, indeed consistent. Therefore, only the results based on cash flow are presented in Figures SVII-5 and SVII-6.

The determination of interest expense is complicated by the fact that it must be calculated from the amount of debt outstanding at the beginning of each quarter. In the first quarter, the only debt outstanding is that used for the purchase of preliminary administration capital (the IS computer). The total capital outlay in the first quarter determines the amount of debt outstanding at the beginning of the second quarter. This in turn determines the interest expense which will be incurred and expensed during the second quarter. In relation to the optimization model flow diagram (Figure SVII-1), debt outstanding is simply given for the first quarter. Thereafter, the cash flow during the  $j^{\text{th}}$  quarter determines the debt and equity outstanding at the beginning of the  $(j + 1)^{\text{st}}$  quarter, and hence the interest expense in the  $(j + 1)^{\text{st}}$  quarter.

The amount of debt and equity outstanding is determined as follows. In any given quarter it is assumed that 50% of total capital needs are borrowed. If cash flow is negative, equity capital must be "put into" the firm in order to make up any deficit. This means that equity capital is needed to finance 50% of total capital needs plus the initial deficits the system can expect in its early years. Figure SVII-2 gives a typical picture of how debt and equity capital change as the system grows. Both debt and negative equity increase until a positive cash flow is attained. Once this happens, negative equity remains constant while the cash flow is used to pay off debt to whatever minimum debt level is chosen (it was \$1,000,000 in this example). When the minimum debt level is reached, the positive cash flow becomes equity "put into" the system. This positive equity builds until the 48th quarter.

### B. Cost Estimates

Cost estimates for a technological innovation are subject to change with operational experience. A major benefit of the computer model of income and cash flow is that such cost changes can be entered into the format easily.

The cost items and assumptions required for the model are outlined below as estimated for 1968. For completeness in presentation, certain items reported in [R-1] are repeated here, but tables and figures from that work are referenced only.

The costs and assumptions described in detail are outlined as follows:

#### Cost Items

1. Capital Costs (vehicles)
  - a. Minicar vehicle cost
  - b. maintenance truck cost\*
2. Operating Costs
  - a. insurance cost
  - b. license/title fees
  - c. parking cost
  - d. direct vehicle operating and maintenance costs and mileage estimates
  - e. car washing cost
3. Identification and Information System Cost
  - a. operating cost
  - b. capital cost
4. Administration and Overhead Costs

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\* At the time of this study maintenance by a specially designed truck was planned.

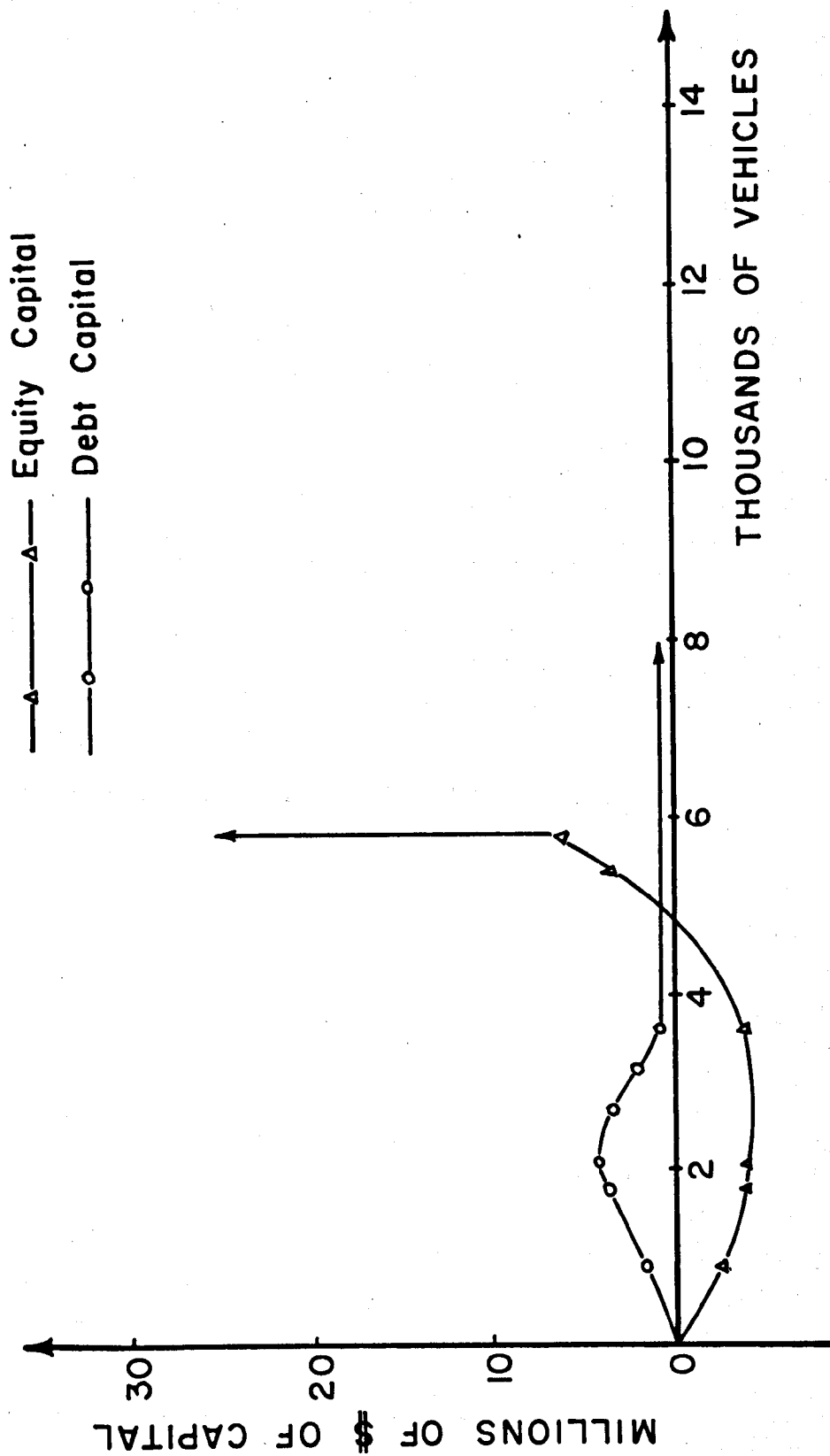


FIGURE SVII-2. DEBT AND EQUITY AS A FUNCTION OF MAXIMUM SYSTEM SIZE



5. Preliminary Administration Costs
6. Interest Expense, Cash-flow Definition
7. Contingency.

Assumptions

8. Delivery of Minicars
9. Depreciation
10. Corporate Income Tax.

1a. Vehicle cost is a function of production volume (the rate of introduction of Minicars into the System). At a rate of 625 cars per quarter the cost per vehicle is estimated at \$3,750, while at a rate of 6,250 cars per quarter the cost per vehicle may be expected to drop to \$2,500.\* These two figures reflect the decreasing average cost per vehicle as the production rate is increased. A linear interpolation procedure was used to calculate other price-rate points due to lack of sufficient information for a hyperbolic fit.

1b. The cost of the maintenance truck is estimated at \$50,000. No economies of scale in its production have been foreseen. The number of trucks was made a function of the number of vehicles by allocating one truck per 625 Minicars.

2a. Monthly insurance costs were estimated at \$25/vehicle times the number of vehicles in operation during the quarter.

2b. License/title fees were estimated at \$20/vehicle/year paid in the first quarter of each year or when the car is first introduced into the System.

2c. Monthly parking costs of \$9.64 per car are estimated from a typical monthly parking rate in the Philadelphia CBD at a conservative parking density increase of 2.8 : 1.0. The Philadelphia monthly parking rate averages \$27/car.

2d. The vehicle operating costs (including gas, oil, maintenance, and tires) were taken from a GM report which indicates VW operating costs are around 2.59¢ per mile[R-1]. A Runzheimer and Company study of typical VW operating costs estimates 2.15¢ per mile. Because of the Minicar Systems's ability to purchase parts and products in bulk quantities at whole-sale rates, the System's operating cost per vehicle is expected to be much lower.

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\* Estimate by Minicars, Inc.; see Technical Supplement S-I, p. 66.

The lowest estimate produced thus far is one of approximately 1.8¢ per mile, which is obtained by recomputing Runzheimer figures for the lower purchase costs. However, since there are major uncertainties regarding maintenance costs, it seems prudent to use the full GM estimate.

Annual vehicle mileage has been estimated at 12,000 miles/car as follows: Assuming the average number of trips/car/day is 11, and assuming the average trip length in the city is 2.5 miles, the average trip-rate mileage per day is 27.5 miles. Adding to this one flat-rate round-trip of 16 miles, we get a total mileage of 43.5 miles per operating day. Assuming 60 operating days per quarter, the total mileage per quarter is 2,610 miles/car. This figure was rounded to 3,000 miles/car/quarter for use in the financial analysis. The number of assumptions used in arriving at the mileage estimate made it an obvious candidate for sensitivity analysis. The profitability of the System proved to be relatively insensitive to operating costs and to mileage estimates.

2e. The cost of washing the cars was assumed to be \$6/car/month.

3a and b. The total cost of the proposed identification and information system is broken down in [R-1, Figure 30, p.58] and the accompanying key [R-1, p. 59]. Total information system costs were made a step-function of the number of cars in the System. For example, if the number of vehicles is between 10,000 and 12,500 the relevant costs are those for the 12,500 car System. Capital costs of the information system are included under depreciation expense when the format is changed from a cash flow to an income statement basis in the computer model.

4. Administration costs are summarized in [R-1, Fig. 34, p.63]. A description of the personnel needed to operate the System is shown in [R-1, Fig. 31, p.60] and the quarterly administrative personal costs appear in [R-1, Fig. 32, p.61]. A description of overhead expenses appears in [R-1, Fig. 33, p.63]; its costs are detailed further in [R-1, Fig. 35, p.64]. These charts are summaries of quarter-by-quarter analyses. Personnel and overhead costs have been made a step-function of the number of cars in the System.

5. One quarter before the system begins operation, installation of computer equipment and terminals, subscriber sign-up and the initiation of general administration begins. These are preliminary administration costs. The capital cost of the computer, \$150,000, is not included under the income statement form since the computer will be depreciated. However, the capital outlay is included in cash flow.

6. Interest expense is calculated by assuming that 50% of all capital costs are financed by borrowing (from a bank) at the interest rate of approximately 9% per annum. The 9% interest rate was the prime rate at the time of the Study. It is possible that the MTS would not be able to borrow from private sector sources at a rate as low as 9%; however, sensitivity analysis revealed the PDV to be insensitive to the interest paid or debt. Debts are paid off by any positive cash flow until the debt drops below \$1,000,000. Cash flow is defined as follows:

$$\begin{aligned}\text{CASH} = & \text{Operating Revenue} \\ & + \text{Borrowing (1/2 of total capital cost in the current period)} \\ & - \text{operating expenses} \\ & - \text{interest expense} \\ & - \text{capital outlays in the current period} \\ & - \text{taxes paid.}\end{aligned}$$

It has been assumed that 50% of all capital was borrowed. Obviously this percentage can change depending on the percentage of total asset value the bank would lend. Major rent-a-car companies are presently able to get up to 80% of the value of their vehicles. 50% is considered to be a conservative estimate on Minicars due to their questionable resale value.

Equity capital is used for one half of capital costs plus any negative cash flow. Negative equity capital represents equity "put into" the project and positive equity capital represents equity "returned" from the project. In the typical system equity decreases at first, then remains constant as positive cash flow is used to pay off debt, and finally increases as the minimum debt point is reached and positive cash flow can be used to be added to the equity account.

7. The contingency has been calculated at 10% of all expenses on the income statement. It has been added to make the cost estimates conservative.

8. In order to estimate cash flow, the assumption is made that additional cars are delivered on the first day of each quarter.

9. Depreciation expense on Minicars is calculated on a 12 year straight-line basis with a \$750 overhaul at the end of the first six years. The overhead is then capitalized and depreciated on a six year straight-line basis. Maintenance facilities are depreciated on a twelve year straight-line basis. The computer equipment is depreciated on a six-year straight-line

basis, repurchased at the end of the first six years and depreciated again. Not all equipment is fully depreciated at the end of the 48-quarter model, but of course the project would continue after twelve years. In most of the simulation runs the system had reached a steady state of operations and could be expected to continue on without any major changes.

10. The corporate income tax rate was assumed to be 48% of gross income. This assumes that the System will take the form of a profit-making corporation instead of a non-profit transportation utility.

### C. Revenue Estimates

Since it is expected that the bulk of the System revenues will be derived from passenger fares, no other revenues were included, in order to make the estimate conservative. Revenue estimates were based on the demand projections developed by the Research Team in the Institute for Environmental Studies. These demand projections are summarized here. They have been duplicated in order to show the specific set of demand assumptions chosen for the computer analysis, and in order to define precisely these demand estimates, which prove to be highly sensitive parameters for financial feasibility.

The revenue estimates presented are subject to change. New marketing studies could easily alter the number of trips diverted. As with the cost estimates, the computer allows the decision maker to rapidly analyze the effect of any change in the parameters.

Revenues are estimated in two categories, trip rate revenue and flat rate revenue:

1. Trip rate revenue is based on the demand projections reported in [R-1], Intra-CBD trips and Intra-Fringe trips are tabulated in [R-1, Fig. 25]; CBD-Fringe trips are tabulated in [R-1, Appendix Table 4]. The assumptions upon which the demand projections were based are summarized below:

a. Approximate present approach time to existing garages was taken as estimated approach time from points in the CBD to Minicar terminals;

b. People value their time at an opportunity cost of \$2/hour;

c. \$.75 parking cost for intra-CBD automobile trips (higher assumed parking costs would enable the Minicar to divert even more trips from other modes of transport);

- d. \$.50 parking cost for fringer-to-CBD automobile trips;
- e. Minicar fare: \$0.25 for first 1.25 miles, plus \$0.25 for each additional mile;
- f. Automobile costs include fixed costs;
- g. Person trips divided by 1.25 gives Minicar trips.
  - (1) Taxi vehicle trips data are available;
  - (2) Auto and transit trips are person trips;
- h. 1975 estimates used;
- i. Only 7:am to 7:pm demand estimates included.

Estimated Minicar trips:

<u>Category of Travel</u>	<u>Diverted from</u>	<u>Minicar trips/day</u>
Intra-CBD	Taxi	5674
	Transit	2380
	Auto	<u>19360</u>
	Sub-Total	27414
CBD - Fringe	Taxi	3715
	Transit	9490
	Auto	<u>33272</u>
	Sub-Total	46477
Intra-Fringe		<u>17816</u>
	Total	91707

Two different demand curves were tested. Based on those curves, the number of trips/Minicar/day was computed as a function of Minicar fleet size. The obtained curves are shown in Figure SVII-3.

The first "high" demand curve was based on the assumption that the total number of Minicar trips increases at a decreasing rate with the fleet size. At approximately 4000 Minicars in the fleet the total demand becomes constant, so that the number of trips per Minicar begins to decrease beyond that point. This is represented by curve a in the Figure. For the second, "low" estimate, it is assumed that the increase of the number of trips is slower in the period when the fleet is small, but it never becomes constant; rather, it continues to grow at a slow rate as the Minicar fleet increases. This demand estimate results in curve b in Figure SVII-3.

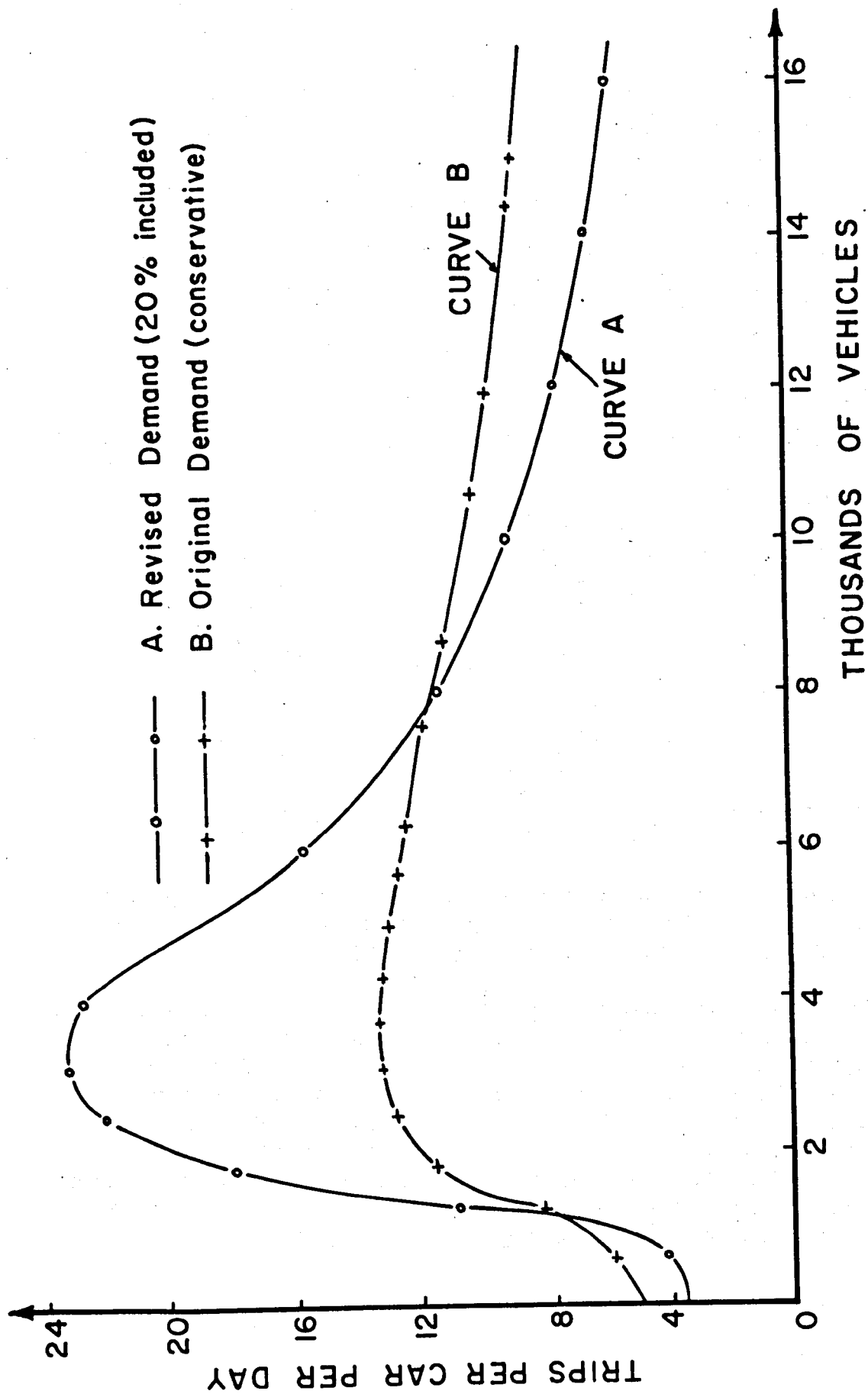


FIGURE SVII-3. MINICAR UTILIZATION AS A FUNCTION OF FLEET SIZE

Trip rate fees were assumed to average \$0.75 per trip. Total trip rate revenue is the average number of trips/car/day times the average fee per trip times 5 days/week, or 60 days/quarter. At least 20% more revenue might be expected from weekend and nighttime usage. Therefore, trip rate revenue estimates are considered to be conservative.

2. The flat-rate option will be initiated only after the System size exceeds 2,500 cars. One flat-rate trip per day (based on a five day week) per car is assumed for each car in excess of 2,500. The first 2,500 cars are assumed to be needed for trip-rate usage within the CBD, or are broken down, or are being redistributed. The flat-rate fee is assumed to be \$75 per car per month.

#### D. System Feasibility

The analysis of system feasibility consists of a sensitivity analysis and an optimization study. The sensitivity analysis was carried out using a simpler version of the financial model presented above. Its purpose was to isolate those cost and revenue estimates most critical to the System, since those parameters are most in need of careful attention in an optimization study. The results of both of these analyses are presented below.

Table SVII-1 presents a typical cash flow result of the type which was presented in [R-1]. Cash flow is calculated by subtracting cash outflows (taxes, capital outlays, interest expense, and operating expenses) from cash inflows (operating revenue plus borrowing). A somewhat more simplified version of the program was used in sensitivity analysis. It was assumed that 625 cars would be introduced each quarter up to a total of 15,000.

Figure SVII-4 shows the result of some of the sensitivity analyses. The quarter when the cash flow turns positive (called the quarter of first gain) and the quarter in which equity capital becomes positive (called the quarter of capital payoff) were observed. Both of these variables proved to be highly sensitive to changes in trip rate and flat rate pricing, although trip rate appeared to be the more significant of the two. The System was also sensitive to changes in the capital cost of the Minicar. However, sensitivity to vehicle operating costs is much lower.

As mentioned before, the complete computer model calculates net income and cash flow for 48 quarters and discounts both figures back into a present discounted value. It then changes the rate of introduction and/or the maximum system size and repeats the cash flow and net income generations.

SPECIFICATIONS

QUARTERS	1.00	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00
MINICARS	625.00	1250.00	2500.00	3750.00	5000.00	6250.00	7500.00	8750.00	10000.00	11250.00	12500.00	13750.00	15000.00
TRUCKS	1.00	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00
TRIPS/DAY/MINICAR-TOT.	5.50	7.50	11.50	13.00	11.50	10.50	9.50	8.50	7.50	6.90	6.25	5.60	5.00
TERMINALS	20.00	42.00	75.00	75.00	100.00	125.00	150.00	175.00	200.00	225.00	250.00	275.00	300.00
EMPLOYEES	32.00	36.00	44.00	49.00	54.00	60.00	68.00	79.00	90.00	95.00	99.00	105.00	110.00
COMPUTER OPERATORS	2.00	2.00	2.00	4.25	4.25	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
TEL. 1-S. OPERATORS	2.00	2.00	6.00	6.00	6.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00

REVENUE

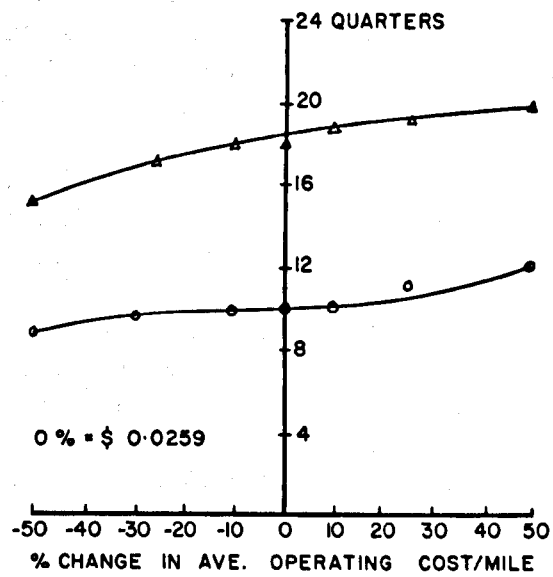
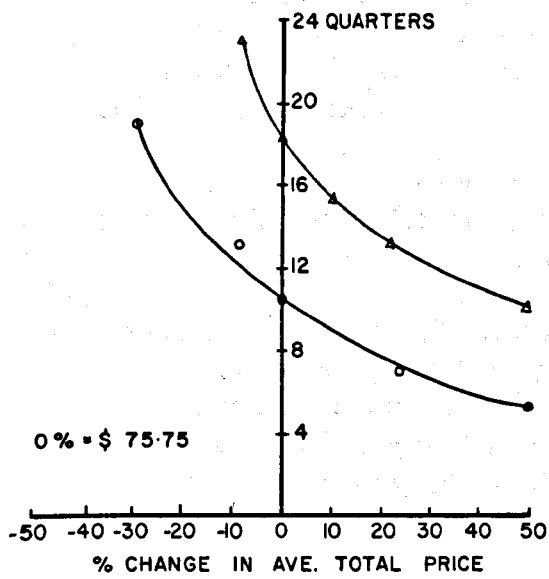
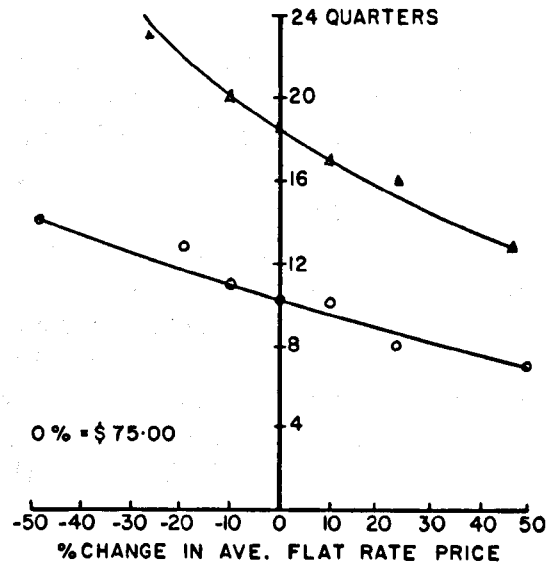
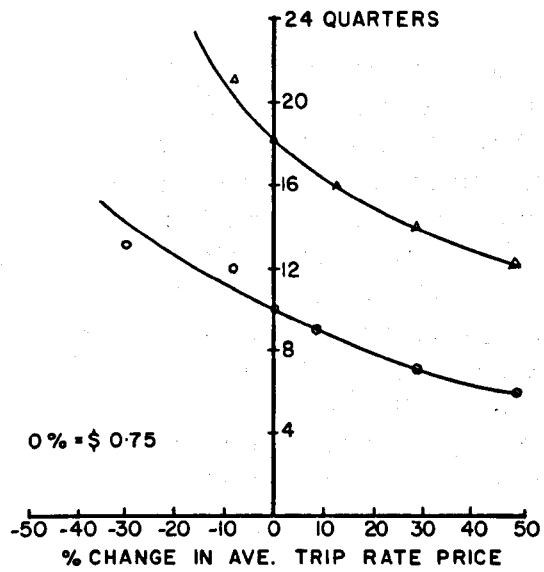
FLAT RATE	0.	0.	0.	843750.	1125000.	1406250.	1687500.	1968750.	2250000.	2531250.	2812500.	3093750.	3375000.
TRIP RATE	154688.	421875.	1293750.	1518750.	1687500.	1828125.	1856250.	2559375.	2475000.	2480624.	2390625.	2227439.	2025000.

COSTS

INSURANCE	46875.	93750.	187500.	281250.	375000.	468750.	562500.	656250.	750000.	843750.	937500.	1031250.	1125000.
PARKING	18075.	36150.	72300.	108450.	144600.	180750.	216900.	253050.	289200.	325350.	361500.	397650.	433800.
DIRECT OPERATING COST	40312.	80625.	161250.	241875.	322500.	403125.	483750.	564375.	645000.	725625.	806250.	886875.	967500.
WASHING EXPENSE	11250.	22500.	45000.	67500.	90000.	112500.	135000.	157500.	180000.	202500.	225000.	247500.	270000.
CAPITAL COST	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.	1612500.
LICENSE FEES	12500.	12500.	12500.	12500.	12500.	12500.	12500.	12500.	12500.	12500.	12500.	12500.	12500.
PERSONNEL	72000.	79000.	93000.	101000.	110000.	121000.	132000.	143000.	154000.	165000.	176000.	187000.	198000.
OVERHEAD	96600.	101533.	111400.	113050.	114700.	117450.	120200.	123550.	126900.	130350.	133800.	137250.	140700.
INFORMATION SYSTEM	126940.	123524.	29300.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
PRELIMINARY ADMIN.	417240.	0.	142323.	197651.	231711.	260031.	282177.	293884.	286629.	286153.	280772.	280071.	277730.
INTEREST COSTS	9388.	57496.	142323.	197651.	231711.	260031.	282177.	293884.	286629.	286153.	280772.	280071.	277730.
10% CONTINGENCY	246368.	221958.	246707.	282547.	311001.	341051.	368594.	395601.	420443.	446513.	471072.	498027.	534663.
TOTAL COST	2710046.	2441533.	2713779.	3108021.	3421009.	3751555.	4054550.	4351608.	4624870.	4911639.	5181792.	5478290.	5881790.
TOTAL REVENUE	154688.	421875.	1293750.	2362500.	2812500.	3234375.	3543750.	4528125.	4725000.	5011874.	5203125.	5321249.	5400000.
TOTAL LOSS	2555358.	2019658.	1420029.	745521.	608509.	517180.	510300.	-176517.	-100130.	-100235.	-21333.	157041.	481290.
ADDITIONAL CAPITAL	2555358.	4575016.	7745509.	9529989.	10906750.	12074130.	13079270.	12885010.	12630060.	12617690.	12457400.	12951080.	13691500.
TAX	36745.	99314.	346562.	673041.	790401.	899926.	972721.	1284452.	1327749.	1400033.	1440636.	1451199.	1447344.

TABLE SVII-1. CASH FLOW EXAMPLE





LEGEND

- QUARTERS OF FIRST GAIN
- ▲—▲—▲— QUARTERS OF CAPITAL PAYOFF

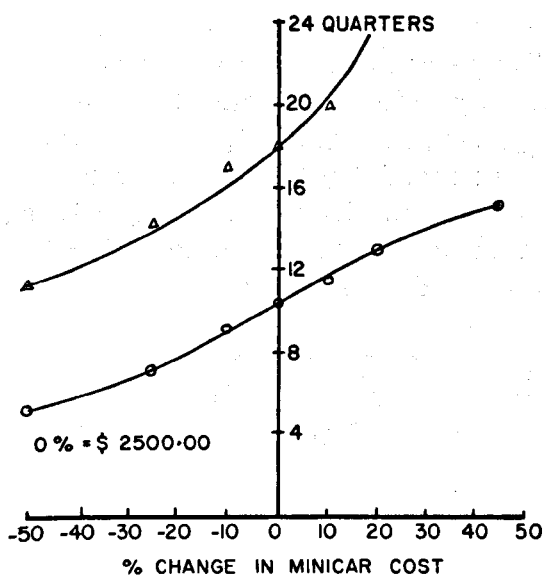


FIGURE SVII-4.  
SENSITIVITY ANALYSIS

The result is a set of PDV sums as a function of rate and fleet size. These figures can be used to locate optimum system size in terms of PDV for each rate of introduction. Figures SVII-5 and SVII-6 show the results of such calculations. Figure SVII-5 uses the revenue assumptions of Figure SVII-3 curve a. Figure SVII-6 uses the more conservative revenue assumptions of Figure SVII-3, curve b. It can be seen that the revenue assumptions significantly affect optimum system size. In Figure SVII-5 a more peaked demand curve results in an optimum system size of about 5,000 cars. However, in Figure SVII-6, a less peaked and more conservative demand curve results in an optimal system size of at least 15,000 cars. The more sophisticated program bears out the sensitivity analysis conclusions from the simpler cash flow model. That is, that the revenue assumptions are a highly sensitive and critical factor in the economic feasibility of the MTS.

Another important result of the analysis is that there is a clear positive relationship between the maximum PDV and the rate of vehicle introduction. Therefore, under actual implementation it will be desirable to build the system up to its optimal operating size as quickly as possible.

The system with maximum PDV will be one with around 5,000 Minicars which are introduced at a rate of 225 cars per quarter. Table SVII-2 shows the 48 quarter computer print-out for this System.

Under either demand assumption it appears that a System of less than 2,500 vehicles would be an extremely risky venture. However, here too, the basic demand assumption is critical. Were the number of trips per car per day a function of the age of the system instead of the number of cars, we might observe 15-20 trips per vehicle per day on a small system. However, such a result would depend on effective vehicle redistribution.

Perhaps the most important finding is the examination of the amounts of debt and equity capital needed to operate a system of any given maximum size and assumed rate of vehicle introduction. These results tell investors how much capital in the form of debt-equity will be needed. Presented below in tabular form is the maximum debt needed, the maximum equity "put into" the system, the maximum debt-equity ratio, the amount of equity "returned" after 48 quarters, and the amount of debt assumed to be outstanding after 48 quarters. Table SVII-3A presents these figures for the demand estimates of Figure SVII-3, curve a and Table SVII-3B presents the figures for the demand estimate of Figure SVII-3, curve b.

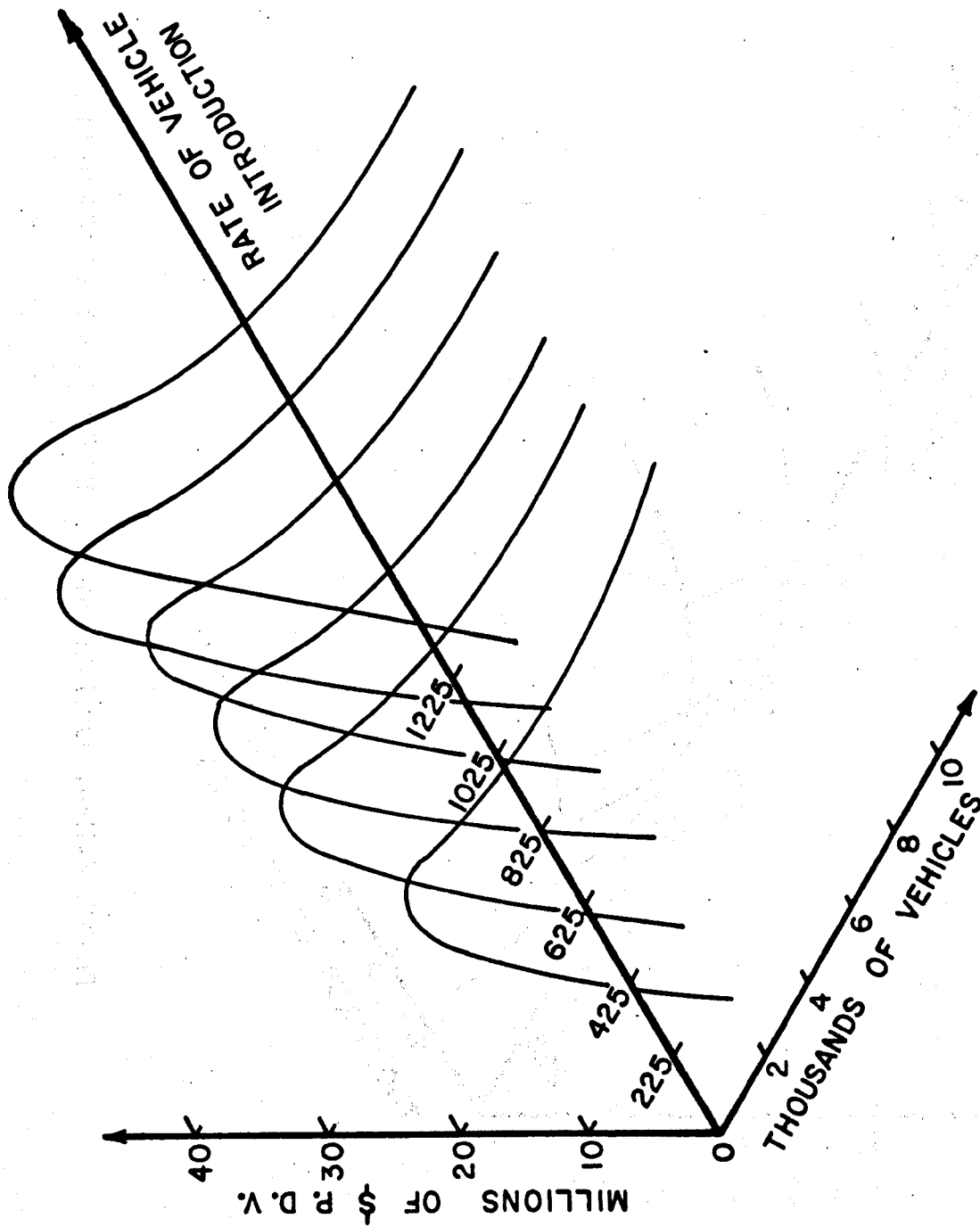


FIGURE SVII-5. OPTIMAL SYSTEM SIZE A (BASED ON CASH FLOW)

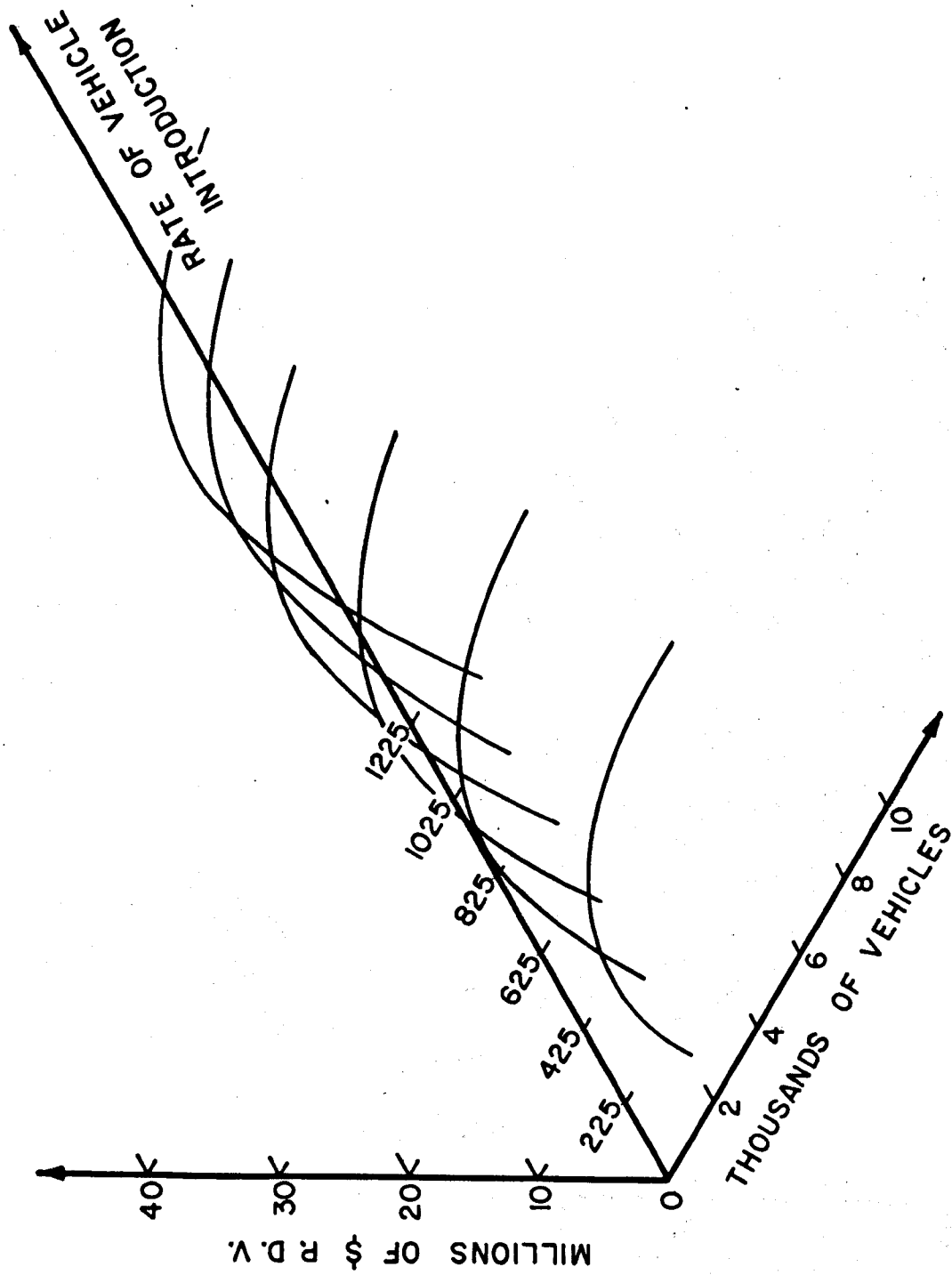


FIGURE SVII-6. OPTIMAL SYSTEM SIZE B (BASED ON CASH FLOW)

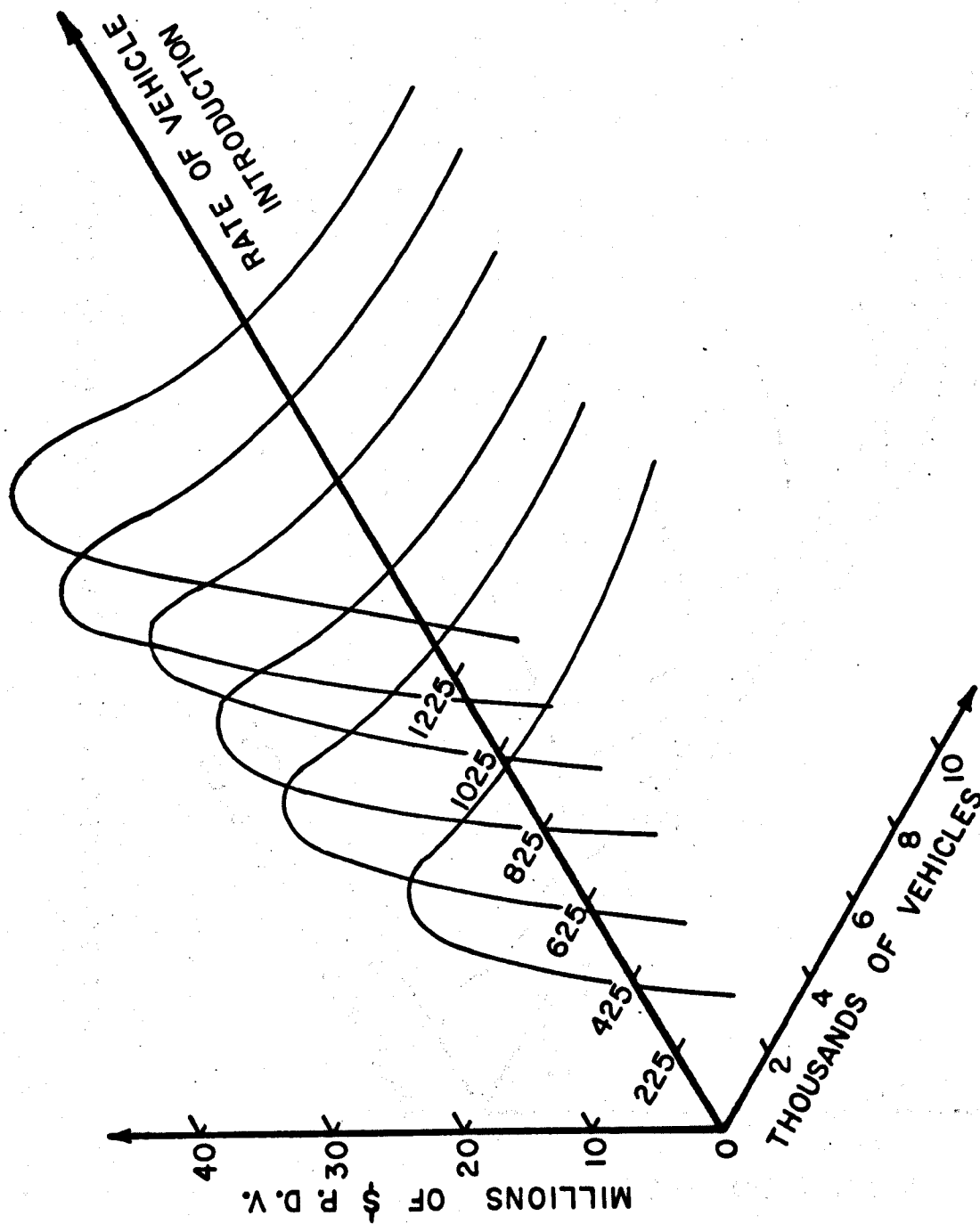


FIGURE SVII-5. OPTIMAL SYSTEM SIZE A (BASED ON CASH FLOW)

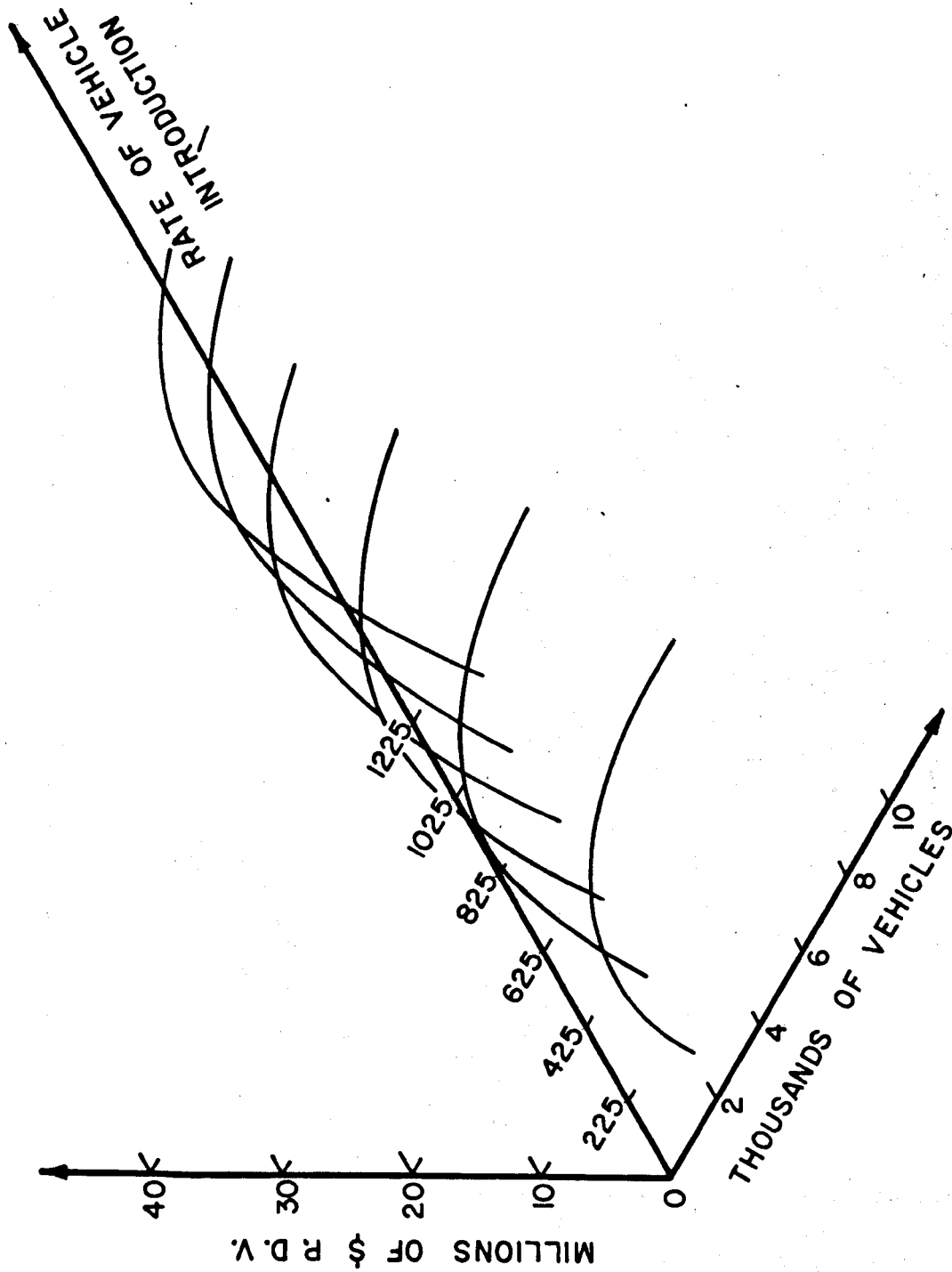


FIGURE SVII-6. OPTIMAL SYSTEM SIZE B (BASED ON CASH FLOW)

## SPECIFICATIONS

QUARTER	1.00	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	44.00	48.00
MINICARS	225.00	900.00	1800.00	2700.00	3600.00	4500.00	5400.00	5350.00	5850.00	5850.00	5350.00	5850.00	5850.00
TRUCKS	1.00	2.00	2.00	4.00	5.00	7.00	8.00	9.00	9.00	9.00	9.00	9.00	9.00
TRIPS/DAY/MINICAR-TOT.	3.60	7.08	17.16	22.38	23.05	21.96	17.72	16.28	16.28	16.28	16.28	16.28	16.28
TERMINALS	7.00	30.00	60.00	82.00	82.00	90.00	108.00	117.00	117.00	117.00	117.00	117.00	117.00
EMPLOYEES	32.00	44.00	54.00	68.00	90.00	99.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
COMPUTER OPERATORS	2.00	2.00	4.25	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
TFL. I.S. OPERATORS	2.00	2.00	2.00	6.00	6.00	6.00	6.00	9.36	9.36	9.36	9.36	9.36	9.36

## INCOME STATEMENTS

FLAT RATE	0.	0.	0.	45000.	247500.	450000.	652500.	753750.	753750.	753750.	753750.	753750.	753750.
TRIP RATE	36450.	286740.	1389958.	2719652.	3733771.	4446897.	4305956.	4235706.	4285706.	4285706.	4285706.	4285706.	4285706.
TOTAL REVENUE	36450.	286740.	1389958.	2764652.	3981271.	4896892.	4958456.	5039456.	5039456.	5039456.	5039456.	5039456.	5039456.
INSURANCE	16950.	67575.	135150.	202800.	270375.	338025.	405600.	439425.	439425.	439425.	439425.	439425.	439425.
PARKING	6507.	26028.	52056.	78084.	104112.	130140.	156168.	169182.	169182.	169182.	169182.	169182.	169182.
DIRECT OPERATING EXP.	17212.	68950.	137700.	206550.	275400.	344250.	413100.	447525.	447525.	447525.	447525.	447525.	447525.
WASHING EXPENSE	4050.	16200.	32400.	48600.	54800.	81000.	97200.	105300.	105300.	105300.	105300.	105300.	105300.
LICENSE FEES	4500.	4500.	4500.	4500.	4500.	4500.	4500.	0.	0.	0.	0.	0.	0.
PERSONNEL	66450.	72450.	72450.	93150.	93150.	93150.	110250.	110250.	110250.	110250.	110250.	110250.	110250.
OVERHEAD	93300.	96600.	96600.	111400.	111400.	111400.	114700.	114700.	114700.	114700.	114700.	114700.	114700.
INFORMATION SYSTEM	15540.	14244.	19644.	38100.	38100.	38100.	38190.	45156.	45156.	45156.	45156.	45156.	45156.
PRELIMINARY ADMIN.	267240.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
INTEREST EXPENSE	17361.	43312.	84431.	81348.	12449.	12449.	12449.	12449.	12449.	12449.	12449.	12449.	12449.
DEPRECIATION EXPENSE	26036.	90746.	155867.	231017.	304177.	378012.	450150.	515006.	543131.	571256.	593381.	627506.	655631.
TAX CONTINGENCY	39015.	49050.	79080.	109555.	127846.	153111.	180230.	195839.	198711.	201524.	204336.	207149.	209961.
TOTAL EXPENSE	418161.	539555.	869877.	1205103.	1406308.	1684226.	1982535.	2154898.	2185826.	2216763.	2247701.	2278638.	2309576.
GROSS INCOME	-381711.	-252816.	520081.	1559549.	2574963.	3212666.	2975921.	2884568.	2853630.	2822693.	2791755.	2760818.	2729880.
TAX	-143221.	-121352.	249639.	748583.	1235987.	1542079.	1428441.	1314592.	1369742.	1354892.	1340042.	1325192.	1310342.
NET INCOME	-198490.	-131464.	270442.	810966.	1339980.	1670586.	1547479.	1490975.	1483887.	1467800.	1451712.	14355625.	1419537.
BANK CAPITAL	540375.	1924998.	3752494.	3615482.	553309.	553309.	553309.	553309.	553309.	553309.	553309.	553309.	553309.
EQUITY CAPITAL	-562.	-2190.	-3970.	-4071.	-4071.	-554.	3592.	9923.	17237.	24610.	32208.	39848.	47466.
CASH FLOW	-974098.	-594892.	-100353.	516834.	1155325.	1523149.	1509394.	1041231.	1956081.	1994931.	2009791.	2009631.	2024481.

PRESENT DISCOUNTED VALUE = 27266224.  
PRESENT DISCOUNTED CASH FLOW = 26753792.

TABLE SVII-2. 48 QUARTER OPTIMIZATION MODEL

Table SVII-3  
DEBT AND EQUITY FOR VARIOUS INTRODUCTION RATES AND "OPTIMUM" SYSTEM SIZES

A. Based on "High" Demand Estimate

Introduction rate	"Optimum" size	Maximum debt * needed	Maximum equity* needed	Maximum D/E	Equity after* 48 quarters	Debt after * 48 quarters
225	5850	4,204	-4,071	1.05	47,466	553
425	5950	6,054	-4,479	1.35	58,510	588
625	5625	7,461	-4,908	1.52	62,897	0
825	5775	12,908	-5,620	2.34	58,066	0
1025	5125	11,897	-6,556	1.81	62,678	326
1225	4900	11,696	-6,896	1.70	65,228	73

\* In thousands of dollars.

B. Based on "Low" Demand Estimate

Introduction rate	"Optimum" size	Maximum debt * needed	Maximum equity* needed	Maximum D/E	Equity after* 48 quarters	Debt after * 48 quarters
225	9,900	6,468	-5,490	1.09	37,020	589
425	13,600	9,367	-6,672	1.40	56,470	747
625	13,750	12,373	-8,121	1.52	56,965	0
825	13,200	17,719	-9,699	1.83	60,698	30
1025	13,325	21,737	-11,643	1.86	62,001	681
1225	13,475	27,980	-13,696	2.04	57,706	0

\* In thousands of dollars.



Further analysis into debt and equity structure of the System can be carried out merely by changing the minimum amount of debt and the percent of total capital borrowed from the bank. Decreasing either of these figures will increase the amount of equity which will have to be "put into" the System before a positive return is realized. Notice that the more conservative demand estimates require a maximum equity investment of almost fourteen million dollars while the less conservative estimates require only about half as much equity - seven million dollars.

#### E. Summary and Conclusions

Based on the demand projections and the cost and revenue assumptions and a simulation analysis of MTS finances for a 12-year period which have been presented above, it can be concluded that the MTS is economically feasible. Amounts of capital investment, however, are large - probably too large for any single private entrepreneur or private institution to undertake alone.

No attempt has been made to perform a quantitative social cost-benefit analysis of the MTS. Conceivably, the same cash flow framework could be used if one were willing to ascribe dollar values to social costs and benefits. Since it is expected that social benefits outweigh social costs, it is likely that the optimal System size would increase when these social considerations are taken into account.

Sensitivity analysis reveals that the demand and revenue assumptions are extremely critical to the success of the MTS. This indicates that it is very important that the demand assumptions be carefully tested and re-evaluated during the experimental phase of the System. The second most critical factor is the cost of the vehicle. However, Minicar capital cost is much less uncertain than demand. Other cost assumptions appear to be relatively uncritical.

Finally, there now exists a computer model of the MTS which may be used as a powerful analytical tool to perform sensitivity and feasibility analyses. Changes in cost and revenue assumptions can easily be incorporated into the model at a fraction of the previous cost in man-hours.

If so desired, the model can be further expanded to include more sophisticated design. For example, it would be interesting to analyze the effect of various pricing policies on the number of trips diverted from other modes of transportation; it would also be desirable to bring vehicle redistribution costs into the general System model; to allow the approach time to terminals to vary with the number of terminals; and, to attempt to quantify social costs and benefits.

## Technical Supplement S-VIII

### LEGAL AND ORGANIZATIONAL ASPECTS\*

#### A. Introduction

The ultimate objectives of this research were: to provide a detailed analysis of the legal considerations which would affect the implementation of the MTS throughout the country; to investigate and assess the advantages and disadvantages of various alternative forms of organization and financing currently available to own and operate such a system; and to make recommendations for appropriate changes in the law including changes in local, state and national regulatory and financial assistance measures.

The immediate objective of this research, as it appeared in the summer of 1969, was to prepare for a 150-car experiment to be carried out in the tri-state region of Philadelphia. Accordingly, the work that was completed in the summer of 1969 and is presented in this Supplement focuses on the tri-state region. The emphasis which was placed on the 150-car experiment affected the priorities of the research conducted in 1969 in one other important way. Since the experiment would be funded, it was then believed, as part of the University research contract and would, in any event, be designed and controlled by the University research team, the considerations which would govern the choice of an appropriate organization to own and operate a full size MTS did not appear to be immediately applicable to the experiment.

Accordingly, the legal research staff chose to concentrate in the first instance on matters which would affect operations, whatever form of organization might be employed for the experiment or, ultimately, for the fully developed system. A general analysis of the alternative forms of organization was prepared early, and is reproduced in section B of this Supplement. This was intended to serve only as a guide to further discussions with local and state officials whose preferences with respect to form would, in any event, have to be considered. Following this approach, discussions were initiated with Southeastern Pennsylvania Transportation Authority to determine whether SEPTA would be prepared to serve as the vehicle for the experiment. On 18 July 1969 official word was received from SEPTA indicating some unwillingness to undertake this function.

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\* The work on the legal and organizational aspects of the MTS was planned for a two-year program, with a staff of one principal investigator and one research assistant. The work was cut short in the fall of 1969 with the termination of the University's research contract.

## B. Organization: General Considerations

### 1. Public Instrumentality vs. Private Corporation

The initial question is whether the MTS should be owned and operated by a public instrumentality, for example by the SEPTA, or by a private corporation. By referring to private corporation, we do not intend at this point to prejudice the question whether this corporation should involve substantial City participation. The distinction we have in mind at this point is between ownership and operation of the system by a governmental authority such as SEPTA or by the City and ownership by a corporation organized under the General Business Corporation Law or under the Nonprofit Corporation Law involving substantial participation by private investors (in the case of a corporation for profit) and by private citizens (in the case of nonprofit). The City can be given a substantial participation in the nonprofit form, as was done, for example with the Philadelphia Housing Development Corporation. There is more difficulty in this regard if the private corporation is a corporation for profit since the articles and by-laws of a business corporation cannot dictate the make-up of the board of directors. However, the City managed to gain substantial control over the Philadelphia Transportation Company which was a business corporation for profit. More on this later.

Focusing on the basic question, it is possible that public ownership will become desirable, when the system has passed the experimental stage and is ready to become fully operational. Certainly the advantages of public ownership must be carefully considered. For the experimental stage, however, the private corporation, for profit or not (depending on various considerations to be explored later) would appear to offer the necessary flexibility. Furthermore, our preliminary research indicates that there is some doubt whether the City or SEPTA has the authority, as the law now stands, to own and operate a system such as envisaged by this proposal. SEPTA, for example, is authorized to operate any "transportation system" within the Philadelphia metropolitan area. Pa. Stat. Ann. tit. 66 § 2004. "Transportation system," however, is defined as a system used for "transportation of passengers for hire," Pa. Stat. Ann. tit. 66 §2003(8). Although the latter words are not further defined, it is doubtful that a user-driven system can be properly characterized as falling within them.

Aside from the political difficulties raised by such a suggestion, there is remarkably little authority for direct City ownership and operation of any motor vehicle transit system. The Home Rule Act of 1949 specifically provides: "no city shall engage in any proprietary or private business except as authorized by the General Assembly." Pa. Stat. Ann. tit. 53 § 13133. The City has statutory authority to own and operate a rail transit system: Pa. Stat. Ann. tit. 53 §§15551 to 15561, but there is no direct

statutory authority for operating a motor vehicle transit system, let alone a user-driven system. A case which arose in Pittsburgh suggests that a bus service might be characterized as a "proprietary or private" business. Pittsburgh Rys. Co. v. Public Service Commission, 115 Pa. Super. 58, 174 At. 670 (1934). On the other hand, a recent Supreme Court decision involving PTC and SEPTA, resting, as it did, on a holding that the City did have the right to exercise an option to purchase PTC (originally negotiated with P.R.T. in 1907), suggests that the City would have the power to own and operate a motor vehicle transportation system. But the court did not address itself to this question but rather to the question whether the option could be exercised after passage of so many years (the City having assigned its option to SEPTA). Southeastern Pa. Tr. Auth. v. Philadelphia Tr. Co. 426 Pa. 377, 233 A.2d 15 (1966).

Certainly, if there is any doubt that the City has authority to operate a bus transportation system, there is a substantial doubt that it may operate a user-driven system. To say the least, operation of such systems is not traditionally a governmental function.

## 2. Private Corporation

In our view the difficulties with public ownership and operation of the System in its experimental stage are such that some form of private corporation is indicated for that stage. The basic question here is whether this should take the profit or the nonprofit form. Clearly different answers may be reached for the initial, experimental stage than for the final, fully operative stage. If a nonprofit corporation proves desirable for the experimental stage, there is no reason why it could not, having completed that stage, transfer its assets to a profit corporation. Although there are numerous reasons for choosing the one over the other, the controlling factor is the source of capital funds. A nonprofit corporation is defined as one which does not involve "pecuniary profit, incidental or otherwise, to its members," Pa. Stat. Ann. tit. 15 § 7002(3). Under this definition, the corporation can borrow capital for its operations but it cannot borrow capital in any form which suggests that the lender has a share in the growth or profits of the corporation. In other words, its capital financing must be strictly debt financing. In addition to debt financing, its only other sources of capital are (a) gifts; (b) grants and reinvestment of its own earnings. Aside from this serious limitation, a nonprofit corporation can operate any business, since payment for goods and services actually rendered to it (even by members) does not violate the above principle. Let us now attempt to list other considerations that are relevant in the choice of form as well as those that are not relevant:

a. Flexibility in Management. A nonprofit corporation by statute and as a practical matter has considerable freedom on how it will govern itself. Its articles and by-laws can provide for a board of directors who

appoint their successors or who are appointed by designated persons (for example by the City) or whose membership on the board is ex officio (e.g. the Mayor). The board may be partly appointive and partly elected by the members. A profit corporation does not have this freedom. Although a profit corporation may issue classes of stock which are non-voting, the statute provides that the board of directors must be elected by the shareholders, Pa. Stat. Ann. titl. 15 § 1401, so that the board cannot be appointive. Furthermore, as a practical matter, few investors can be expected to venture capital in an equity position without some control over the board.

b. State and Local Taxation. A nonprofit corporation is exempt from State capital stock tax, Pa. Stat. Ann. tit. 72 § 1871 (currently 5 mills). Otherwise, a nonprofit corporation would be subject to all of the State and local taxes which can currently be levied against a profit corporation. We are unable to say at the moment, whether the corporation operating the MTS would be subject to the gross receipts tax on motor carriers under Pa. Stat. Ann. tit. 72 § 2183 (8 mills on the dollar) since that provision refers to corporations which engage in the business of "carrying passengers or property for hire." However, if the tax is applicable, it is applicable both to the nonprofit and to the profit corporation. There is a difference between the two forms in regard to taxes that relate to net income. Ordinarily, a nonprofit corporation is able to match its income and deductions (including interest on loans and depreciation) in such a way as to show no net income. This brings us to the next point:

c. Federal Income Taxation. It is doubtful that the corporation operating the MTS will qualify as a tax exempt organization even in the nonprofit form. The nearest provision is I.R.C. §501 (c) (4) which grants an exemption to "organizations not organized for profit but operated exclusively for the promotion of social welfare." There is a revenue ruling, Rev. Rul. 64-187, 1964-1 CB (Part I) 354 which may be encouraging. But the Treasury is unlikely to favor an exemption for a private user-driven system unless the system has strong social welfare features. See Commissioner v. Lake Forest Inc. 305 F. 2d 814 (4th Cir. 1962) (denying an exemption to a low income cooperative). An exemption may be easier to obtain for the research and experimental stage, particularly if there is substantial government involvement during that stage.

If an exemption cannot be obtained, the corporation may not incur any tax liability if it can match its income and deductions so as to show little net taxable income. This matter will have to be considered further as the financing and operational plans become more fully developed.

d. Control over Policy and Profit. The nonprofit form clearly offers more control over the policy of the system, if ends other than maximization of profit are to be served. The value of the profit incentive should not be disregarded, however. Our present conclusion is that the nonprofit form is suitable only to the experimental stage and that the system should be taken over by a profit corporation or by a public authority--otherwise it may wither on the vine.

If the system is placed in the hands of a profit corporation, the existing public controls over policy may not provide adequate assurance that the system will serve the goals established by this study. For example, assuming that the Public Utilities Commission has jurisdiction (see Part C. infra ), it will exercise some control on profit, but in terms of policy its traditional stance is in favor of equality of treatment as to areas of service and persons served and against competition between carriers as to rates and areas of service. In public transportation, PUC is accustomed to deal with systems which are either largely random or non-selective as to areas and persons served or with systems which have fixed routes. The proposed user-driven system will deal with applicants who desire a continuing contract relationship with the system. In private hands, the risks involved in turning a vehicle over to the applicant, offer a strong argument for substantial discretion in approving or rejecting the applicant. PUC is not accustomed to deal with this kind of a system. For precisely this reason, the courts have generally held that user-driven operations are not public carriers and are not subject to PUC control. See discussion in Part C. infra.

The point is that even if PUC jurisdiction were clear, its supervision of the system may not secure some of the policy goals that may be found desirable by this study--for example, service in the poverty areas of the City. Subject to further study of this problem, new legislation may have to be developed to furnish the appropriate measure of public control if the system is operated by a profit company. The other alternative, of course, is to find or to create an appropriate public agency to own and operate the system.

### C. Government Control of MTS

#### 1. Interstate Commerce Commission (I.C.C.)

Whatever its form of organization, if the MTS recruits Philadelphia commuters from New Jersey and Delaware, the System may be operating as a

"common" or "contract carrier by motor vehicle" in interstate commerce; if so, the I.C.C. may regulate it under the Motor Carrier Act of 1935. 49 U.S.C.A. §§ 301-327. Significantly, the regulatory power given to the I.C.C. by Congress over any subject matter within its commerce powers, is exclusive, so that a state may not exercise concurrent jurisdiction. This power extends over all interstate carriage, and intrastate carriage integral to a continuous flow of interstate traffic (leaving regulation of remaining intrastate carriage to the states). Castle v. Hayes Freight Lines, Inc., 348 U.S. 61 (1954); U.S. v. Capital Transit, 338 U.S. 286 (1949); Maurer v. Boardman, 336 Pa. 17, 7 A2d 466, aff'd 309 U.S. 598 (1939); Pa. Stat. Ann. tit. 66 § 1532. It is highly unlikely, however, that the MTS, as its operation is now envisaged, will be subject to I.C.C. jurisdiction. There are some details of the operation that might affect this conclusion. These are noted below.

A "common carrier by motor vehicle" is defined in the Motor Carrier Act as "any person which holds itself out to the general public to engage in the transportation by motor vehicle in interstate or foreign commerce of passengers or property or any class or classes thereof for compensation, whether over regular or irregular routes. . . ." 49 U.S.C.A. § 303(a)(14). A "contract carrier by motor vehicle" is defined as "any person which engages in transportation by motor vehicle of passengers or property in interstate commerce, for compensation (other than transportation referred to in paragraph (14) of this subsection. . .), under continuing contracts with one person or a limited number of persons. . . ." 49 U.S.C.A. § 303(a)(15). A publicly-owned system may be such a common or contract carrier. The Act defines a "person" to include a corporation. 49 U.S.C.A. § 303(a)(1). Thus a public "body corporate and politic" such as SEPTA, insofar as it engages in business of a private nature and solicits passengers for its vehicles, will be classified as such a "corporation" for purposes of the Act. cf. Ohio v. Helvering, 292 U.S. 360 (1933). It is noteworthy that the legislation creating SEPTA specifically enables it "to petition the Interstate Commerce Commission." Pa. Stat. Ann. tit. 66 § 2004(a) and (d)(2). To what extent does the MTS fit the above definitions of common and contract carriers by motor vehicle?

First, if the lessee of a Minicar uses it to transport passengers or the property of another person across a state line for compensation, the lessee will be operating as either a common or contract carrier, and he may be regulated as such. This type of operation is more likely to occur if a Minicar costs considerably less than a taxicab. Moreover, even if the lessee transports his own goods in furtherance of any commercial enterprise,

he becomes subject to I.C.C. safety regulations. 49 U.S.C.A. §§ 303(17) and 304(3). To avoid problems for the MTS, it is advisable that lessees be notified and agree in advance not to engage in such transportation. For example, if MTS leases to an individual who is operating as a common or contract carrier without I.C.C. permission, it may become subject to punishment for "knowingly and willingly by any means or otherwise fraudulently seek(ing) to evade or defeat regulation as in this chapter provided for motor carriers...." 49 U.S.C.A. § 3222.

Second, even if lessees use the Minicars solely for personal business or pleasure, MTS may be subject to regulation as a common or contract carrier, since the Motor Vehicle Act of 1935 applies not only to those who transport in interstate commerce, but those who provide the facilities for such transportation. 49 U.S.C.A. § 302(a). Not all "persons" who rent motor vehicles are subject to regulation under this provision, however. Rather, only those which retain control over the leased vehicle, or in substance provide a transportation service, are classified with common and contract carriers. U.S. v. Drum, 368 U.S. 370, 384 (1962); H.B. Church Truck Service Co., 27 M.C.C. 191 (1940). Since this distinction fairly invites subterfuge, the I.C.C. has established a rebuttable presumption that transportation will be considered "for-hire" if any equipment is furnished. H.B. Church Truck Service Co., *supra*.

One of the facts which may rebut the presumption is "a showing that the...equipment (was) operated by the shipper's (lessee's) employee." H. B. Church, *supra*, pp. 195-6. Because the MTS does not provide drivers, we believe that it will fall outside the class of "for-hire" carriers. See Oklahoma Furniture Mfg. Co., 79 M.C.C. 403, 410 (1959). MTS confines the right to operate its vehicles to its card holders. If licensed drivers are extensively screened before cards are issued to them, MTS will be exerting more control over operation of its vehicles than other user-driven systems.

In addition to physical control over the vehicle, unnecessary assumptions of risk or of responsibility by the owner have been considered significant indices of control. Pacific Diesel Rental Co., 78 M.C.C. 161, 173 (1958). Some states by statutes provide that the owner of a leased vehicle must assume all responsibility for its operation. (See Part C.3. *infra*). However, if MTS should voluntarily assume responsibility for anything besides its own negligence, it will come closer to being classified as a carrier. Assumption of risks other than those vis a vis the public



may bear on this issue. In U.S. v. Drum, supra the lessor bore risks of premature depreciation, catastrophic loss, rise in variable costs such as fuels and maintenance, and transportation hazards such as detours. Although the lessor also provided the drivers, the court emphasized these additional assumptions of risk in holding it to be a common carrier.

On the question who is providing the transportation service, a final significant element is which party determines the route and timetables. In I.C.C. v. Davidson, 20 F. Supp. 832 (1937), a second-hand auto dealer who delivered his cars to other states through licensed drivers who were looking for inexpensive personal transportation, was declared a common carrier. Although he did not provide the drivers, he selected his customers carefully, and stipulated where and when they had to deliver the car.

In short the MTS will not be subject to I.C.C. regulation, so long as its manner of operation suggests that it is leasing equipment rather than providing a transportation service without a driver. U-Drive-It Co. of Pennsylvania, 23 M.C.C. 799 (1940), was a company which furnished cars without drivers to individuals for their personal use, furnished gas and oil, maintained the equipment, and maintained liability and property damage insurance while assessing customers for the cost. It was held exempt from I.C.C. regulation.

Finally, if the I.C.C. jurisdiction should attach to the MTS, an exemption, 49 U.S.C.A. §303(b)(8) may allow Minicars to operate freely within a defined "commercial zone" around Philadelphia. This zone has a complex boundary, and includes parts of Bucks-Montgomery, and Delaware Counties in Pennsylvania, and Camden as well as other boroughs and townships in Camden County, New Jersey. See Philadelphia, Pa. Commercial Zone, 17 M.C.C. 533 (1939), 74 M.C.C. 633 (1958), 94 M.C.C. 172 (1963). Needless to say, such a limitation would restrict the scope of the project.

## 2. Pennsylvania Public Utility Commission (PUC)

a. SEPTA Operation of the MTS. Although SEPTA is authorized by statute to own and operate a "transportation system" both within and without its specified "metropolitan area," all services rendered by the authority outside the metropolitan area shall be pursuant to certificates of public convenience or other appropriate authorization issued to it by the

Pennsylvania Public Utility Commission or other appropriate regulatory agency...." Pa. Stat. Ann. tit. 66 § 2004(a). What is implied by this provision is that within SEPTA's metropolitan area, its systems are exempt from PUC regulation, just as a municipal utility is exempt from regulation except for "service being furnished...behond its corporate limits." Pa. Stat. Ann. tit. 66 §§1141 and 1171. Since the Philadelphia metropolitan area includes Philadelphia County and all counties "located in whole or in part within twenty (20) miles" of it, Pa. Stat. Ann., tit. 66 § 2003(a)(5), these boundaries may not limit use of the Minicars excessively. However, if this limitation should prove unworkable, there is an argument which would permit SEPTA to make wider use of the Minicar.

A municipal-owned utility is exempt from PUC regulation when servicing within the municipality because another means of regulating it exists--the ballot box. On the other hand, "It is the consumer outside the corporate limits who has no right to participate in the government of the municipality and, therefore, in its selection of management, who needs protection against the natural inclination of management to favor its constituents at the expense of the outsider who has no voice." State College Borough Authority v. P.U.C., 152 Pa. Super. 363, 31 A.2d 557 (1943). Thus, municipal-owned utilities are regulated when operating outside their corporate limits because they are more likely to be serving large numbers of people who are not constituents (as with a water or gas system). Evidently, the same assumptions and judgments have been made with respect to metropolitan systems, where heads of the counties involved appoint the members of the transit authority boards. Pa. Stat. Ann. tit. 66 § 2016(a)(2).

Interpreting the statute in light of this rationale, in the operation of a bus or trolley there is no time to discover the address of each person served; so the restrictions on municipal and metropolitan utilities should logically depend on where the service takes place. But given the unique organization of the MTS, it would be in a position to know at all times whom it is serving and where that person resides. Thus, it may be possible to avoid PUC regulation, regardless of where the cars are driven, so long as all Minicar subscribers reside within the metropolitan area.

The question remains, however, as to whether SEPTA is authorized to operate the MTS as a "transportation system." Pa. Stat. Ann. tit. 66 § 2004(a). Such a "system" is merely "property...useful for the transportation of passengers for hire." Pa. Stat. Ann. tit. 66 § 2003(8). And although the words are not further defined, "for-hire" transportation usually refers to both common and contract carriers. Limiting this definition further

is Pa. Stat. Ann. tit. 66 §2005, which permits SEPTA to purchase the facilities of "public utilities" only. Pa. Stat. Ann. tit. 66 § 1102(17)(c). Consequently, SEPTA may not be authorized to own and operate the MTS unless it is a system which would properly be characterized as a "public utility" -- subject to PUC control if privately owned.

b. MTS Privately Owned.

(i) Uncertainty of Jurisdiction: Pennsylvania law defines a "common carrier (person who undertakes service to the public for compensation) who or which holds out or undertakes the transportation of passengers...or any class of passenger...between points within this Commonwealth by motor vehicle for compensation...or who or which provides or furnishes any motor vehicle, with or without a driver, for transportation or for use in transportation of persons...." Pa. Stat. Ann. tit. 66 § 1102(6) (Emphasis added). The definition of a "contract carrier by motor vehicle" is the same, except "person or corporation" is substituted for "common carrier." Pa. Stat. Ann. tit. 66 § 1102(7). From the wording of these definitions, it would appear that the MTS qualifies as an entity which provides motor vehicles without drivers for transportation or for use in transportation.

Determining jurisdiction may not be that simple, however. For in 1943 the Pennsylvania legislature evidently believed that the business of renting motor vehicles could only be regulated by passing a special amendment to the Public Utility Code. Such an amendment was passed, and later declared unconstitutional. Pa. Stat. Ann. tit. 66 §§ 1731-41; Hertz Driveurself Stations, Inc. v. Siggins, 359 Pa. 25, 58 A2d 464, 7 ALR2d (1948). Both the legislature and the courts distinguished the rent-a-car operation from common and contract carriage. The preamble of the amendatory Act recites that both common and contract carriers "are subject to regulation under the Pennsylvania Public Utility Law" and that "the renting of motor vehicles to the public competes with the businesses of common and contract carriers by motor vehicle." The Court of Common Pleas found that "(Hertz) is not acting either as a common or contract carrier, and does not compete substantially with common or contract carriers by motor vehicles...." Quoted in Hertz, supra at 30, 468, 444. The Pennsylvania Supreme Court agreed, frequently describing Hertz's activity as a "private business." The only reason given for this conclusion, however, was that Hertz does not purport to serve the public at large because it selects its customers. Hertz, supra, at 35, 472, 448. While this reason may be persuasive on the question whether Hertz is a "common carrier," it does not dispose of the question whether Hertz is a "contract carrier." Indeed, it has been recognized in other cases that selectivity as to customers is one of the chief differences between a "common carrier" and a "contract

carrier" Merchant's Parcel Delivery v. P.U.C. 150 Pa. Super. 120, 126, 28 A 2d 340, 343 (1942). Furthermore, the court in Hertz plainly recognizes that the legislature has power to regulate "contract carriers."

Since the Pennsylvania legislature clearly intended to cover some, if not all, rent-a-car systems by using the language "with or without a driver," and since selectivity alone cannot be the attribute that takes a rent-a-car system outside the regulatory power, the most that we can conclude from Hertz decision is that some rent-a-car systems are not within the regulatory power, the remaining question being what are the attributes which make the difference between inclusion and exclusion--a question which is not adequately answered by the court in Hertz. We can certainly assume that, whatever these attributes are, Hertz had those that would make for exclusion--since the court held plainly that Hertz cannot be regulated. The point here is that Hertz does not exclude the possibility that some rent-a-car systems not only may be, but are, regulated by the Public Utilities Code of Pennsylvania.

So far as the attributes which determine inclusion or exclusion under the Pennsylvania public utility law are concerned, it is fair to assume that they are the same as those which are decisive for other regulatory agencies, particularly the I.C.C. (See C.I. supra). The Court in Hertz cites cases from several states which, like the I.C.C., regulate only lessors of driverless cars who retain control of the vehicles or "provide a transportation service." Thus in an Arkansas case the lessee operated the cars "at his own risk and discretion," and the lessor was held not to be a common carrier. State v. Dalaney, 176 Ark. 1071, 5 S.W.2d 304 (1927). And the Florida Supreme Court appraised the status of lessors of vehicles without drivers as follows: "...they simply enter into a contract or bailment with an intended customer, which completely divorces the bailor from all further control or responsibility in connection with the operation of the automobile while it is in the hands of the bailee." Lawrence v. Goddard, 124 Fla. 250, 168 So. 13, 14 (1936). Although neither Arkansas nor Florida explicitly provides in its definitions of common and contract carriers for the furnishing of vehicles without drivers, these cases are nevertheless relevant to an interpretation of the Pennsylvania law. It is not implausible, for example, that Pennsylvania has created a class of carriers which these other states either exclude or have not considered -- lessors of driverless vehicles who do retain control--but that Pennsylvania still excludes from regulation that class which other states exclude -- lessors of vehicles who do not retain control.

There is some indication in the public utilities law itself that the legislature was concerned with distinctions between types of lessors. The definitions of common and contract carriers exempt "(a) a lessor under a lease given on a bona fide sale of a motor vehicle where the lessor assumes no responsibility for maintenance, supervision, or control of the motor vehicle so sold." Pa. Stat. Ann. tit. 66 §1102(a)(6) and (7). It is difficult to assess the implications of this exemption. One implication is that any other lessor who assumes responsibility for maintenance is not exempt, which would bring Hertz squarely within the definition of a common or contract carrier, contrary to the decision in the Hertz case. For the court held in Hertz both that Hertz was not a common or contract carrier, and that "it does keep (its vehicles) in repair and good running order and furnishes garage facilities and services, tires, oil and other lubricants." Hertz, supra at 30, 368, 444.

Alternatively, the fact that the exemption is limited to lessors under a lease-purchase arrangement, and the fact that such lessors are required to sever all association with the vehicle in order to entitle themselves to the exemption, suggest that the legislature may have been addressing itself to a specific loophole in the existing distinction between rent-a-car operations which may and those which may not be regulated. It is possible that lessors under lease-purchase arrangements were exerting sufficient control over their vehicles, so that they would be subject to regulation if they were regular lessors; but since the contract between lessor and lessee was also a sales contract, the PUC was unwilling to classify them as providing a transportation service. Accordingly, the legislation may have been designed to single out these lease-purchase lessors, in such a way that they could only be exempted from regulation if they turned the vehicle over to the lessee completely. The difficulty with this theory is that it does not explain why a lessor in a lease-purchase arrangement would be prohibited from providing maintenance if it was to be exempt, yet a regular lessor, like Hertz, is clearly allowed to do so. The words "supervision" and "control" pose no such problems, since under most circumstances, a regular lessor, like the lease-purchase lessor, may not retain supervision or control and remain exempt.

Since Pennsylvania case law does not specify the amount and kinds of control a lessor is allowed to retain without falling within the definitions of common and contract carriers, some systems choices by the MTS could cause the operation to become subject to PUC regulation (See C.1. supra, for the I.C.C.'s more precise guidelines).

(ii) The distinction between "common" and "contract" carrier.

Assuming regulation becomes a reality, the question arises whether the MTS will be regulated as a common or contract carrier, since the PUC has more extensive powers over the former.

Essentially, a common carrier is distinguishable from a contract carrier in that it serves the public "indiscriminately." However, the courts have allowed common carriers to discriminate on the basis of several criteria, without losing their status. A common carrier need not serve everyone. Common carrier service can be limited by its capacity, by the market, by the carriers routes, and by the classes of passengers and/or property it is equipped to carry. Primrose v. Casualty Co., 232 Pa. 210, 81 A. 212 (1910); York Motor Express v. P.S.C.; 96 Pa. Super. 174 (1929); Erb v. P.S.C., 93 Pa. Super. 421 (1928). With all these limitations, courts usually determine that a carrier is open to the indefinite public and does not confine itself to select individuals, on the basis of its advertising, extent of its service, and similarity of service to all. If the MTS publicly offers to serve everyone who has a driver's license, it will be serving a large uniform class of passengers, which would put it within the definition of a common carrier. If driving records, for example, are taken into account in approving applicants, MTS will look more like a common carrier if it establishes some kind of point system for rating driver's and utilizes a uniform cut-off than if it makes a subjective judgment as to each applicant. Similarly, uniform regulations as to users' income and credit may be consistent with MTS serving as a common carrier, because of unique characteristics of the Minicar System. In most forms of transportation you pay, then go. In others like taxicabs you go, then pay; but the driver has you within his control in case you do not pay. Since the MTS cannot capture immediately the people who do not pay bills, it is reasonable and consistent with the "ability to pay" doctrine that MTS be allowed a precheck for income information, provided again that its cutting-off point is not too high. Primrose v. Casualty Co., supra. These uniform standards may be imposed as conditions of the certificate of public convenience issued by the PUC. Pa. Stat. Ann. tit. 66 § 1123(a); Merchants Parcel Delivery v. P.U.C., supra at 137, 347 (dissent). Undoubtedly, however, no matter how uniform are the limitations on who may rent Minicars, as the number of restrictions increase, excluding more and more of the public, the chances increase that the system will be classified as a contract, not a common, carrier.

If, however, the MTS is classified by the PUC as neither type of carrier, there is still the possibility that regulation of the Minicars by special amendment will be more successful than it was in the Hertz case. The court held in Hertz that a transportation business which is not a common or contract

carrier may be regulated under the general police power of the state only if it is "affected with a public interest," and the regulation is in fact in the public interest (not merely in the interests of common or contract carriers). A business so qualifies if it makes an "intentional and deliberate dedication of private property to public use." Hertz, supra, at 34, 370, 446. Hertz was found not to satisfy this criterion; there is a stronger case that the Minicars do satisfy it. If few restrictions are placed on who may use them, they may be said to be dedicated to public use. Moreover, they are being designed with public as well as private benefit in mind--relief from pollution, traffic and parking congestion.

To conclude, the MTS is clearly a borderline case.

c. How to Proceed Before the PUC . Because of uncertainty, the risks, should MTS begin its operation without approval from the Commission, are fairly substantial. If operation begins without PUC approval or an order stating that it does not have jurisdiction, the consequences which may follow are:

(i) PUC may apply directly to the Court of Common Pleas for a permanent injunction against the MTS, and a preliminary injunction pending the final decision. Pa. Stat. Ann. tit. 66 § 1343. PUC would not have to post a bond to obtain this injunction. Operation of Minicars would cease, at least pending the final decision.

(ii) Either the PUC or any interested party may file a complaint with the Commission, thereby initiating a hearing to decide whether the MTS has operated as a common or contract carrier without PUC authorization. Pa. Stat. Ann. tit. 66 § 1391. Either complainant could obtain an injunction from the Court of Common Pleas to preserve the "status quo" pending the outcome of the hearing or an application by MTS for PUC authorization. Pa. Stat. Ann. tit. 66 § 1343; Fogelsville v. Pennsylvania Power and Light Company, 271 Pa. 237, 114 At. 822 (1921). Unfortunately, the "status quo" here means the status quo existing before the allegedly wrongful operations were begun--in our case, meaning complete stoppage. P.U.C. v. Israel, 356 Pa. 400, 52 A. 2d 317 (1947). If the action is brought by private parties, it is noteworthy that they would be required to post bond as a condition to obtaining an injunction (a factor which may discourage spurious claims) Pa. Stat. Ann. tit. 12 § 1076.

Whether or not this injunction is secured, the suit will be dismissed if, within a specified time, the complaint is "satisfied" by an application to the PUC Pa. Stat. Ann. tit. 66 § 1393. It is doubtful, however that the Minicars will be allowed to operate during the time when the application is being considered; the MTS may be required to swear in its application not to engage in transportation pending PUC's decision. Pa. P.U.C. Rules of Practice, p. 6.

If MTS decides not to "satisfy" the complaint by making an application but rather to challenge PUC jurisdiction at the hearing, or if MTS applies but is turned down on the merits, the Commission may issue an order, enforceable by injunction, stopping all operations until its authorization is obtained. Pa. Stat. Ann. tit. 66 §§ 1395, 1343. After such an order is issued, the MTS may be able to obtain an injunction annulling the order only on the grounds that PUC has no jurisdiction. Pa. Stat. Ann. tit. 66 § 1441. Alternatively, it may appeal on the merits, such an appeal acting as a supersedeas--staying the effect of the order--only in the discretion of the judge, who may then require MTS to post bond. Pa. Stat. Ann. tit. 66 § 1433.

These complicated procedures demonstrate how the MTS may be harmed by waiting for others to act in an uncertain situation. Operation may be stopped, or details of the System may be changed as conditions to the PUC granting its authorization. Either occurrence could seriously disrupt the MTS.

(iii) MTS may be penalized for operating without a certificate of public convenience, the company, its officers and employees could be penalized by fines from \$26-300 and up to thirty days in prison for the first two convictions, and by fines from \$300-500 and up to six months in prison, for subsequent offenses.

It is possible for MTS to take a middle-of-the-road course. It could make an application to the PUC before beginning operation and take the position both that PUC has no jurisdiction and that, if it does, the application should be approved. If the Commission decides that MTS is within its jurisdiction and then denies the application on the merits, MTS can appeal the ruling on the merits or on the jurisdictional issue under § 1431. Alternatively, if MTS were to prefer not to reach the merits of its application, but rather, challenge the ruling on the jurisdictional issue, it could proceed to do so under § 1441. The cases indicate, however, that only third parties objecting to an application have taken advantage of this provision. Reed v. P.U.C., 174 Pa. Super. 132 (1954). More importantly, there is nothing in the statute, or the cases, which would indicate that a party cannot both apply for a certificate to operate and challenge the Commission's jurisdiction, in the alternative.



d. Consequences of PUC Regulation. The power which PUC has over rate-fixing is potentially the most disrupting for the MTS. In particular, proposed fares for the U-Drive-It Taxi service apparently must be competitive with regular taxicabs, or the public will not use the Minicars. October, 1968 Proposal, page 17a. If the Minicars are classified by the PUC as "contract carriers," the Commission is authorized to set minimum rates which are higher than those desired by the MTS. Pa. Stat. Ann. tit. 66 §§ 1302 and 1310. The purpose behind PUC prescribing such rates is to protect common carriers from cutthroat competition and pricecutting on the part of contract carriers, as well as to protect contract carriers from each other. Betterman v. American Stores Co., 367 Pa, 193, 80 A2d 66, cert. den. 342 U.S. 827(1951). In the case of "common carriers," the Commission may only bar rates which are not "just and reasonable." Pa. Stat. Ann. tit. 66 §1141. Although the case law does not clearly define what makes a rate unreasonably low, there are indications that a rate is acceptable so long as it is high enough to allow the company a minimal return on its money, and it has not been temporarily lowered for the purpose of destroying competition. For example, proposed rates are not even to be considered by the Commission in ruling on a common carrier application, unless they are clearly "noncompensatory," and the Commission has reason to believe that competitive use of such low fares would be inimical to the public interest. Railway Express Agency v. P.U.C., 195 Pa. Super. 92, 169 A2d 798(1961). It is also clear that "within the zone of reasonableness," common carriers may voluntarily reduce their rates for the purpose of attracting traffic to their systems. Such reductions are viewed favorably by the PUC when one mode of transportation is competing with another, since, generally speaking, the PUC finds it in the public interest for people to be able to choose the mode most convenient for them, and within their price range. Pennsylvania Railroad Co. v. P.U.C., 199 Pa. Super. 158, 184 A.2d 111 (1962); Pennsylvania Railroad Co. v. P.S.C. 126 Pa. Super. 1, 11, 190 A. 372, 376 (1937). As U-Drive-It Taxis may serve different needs than regular taxicabs--since they are more easily accessible; have different arrangements for payment, etc.--it seems likely that if the system is classified as a common carrier, it will be allowed to compete with taxicabs and other forms of public transport.

### 3. New Jersey and Delaware Public Utility Commissions

Assuming that neither the I.C.C. nor Pennsylvania's PUC have jurisdiction over the MTS, there remains the problem of regulation by other states into which Minicars are likely to be driven. For if Congress does not assert jurisdiction over interstate commerce, the states through which such commerce flows may regulate it within their boundaries (See C.1, supra). In addition, if New Jersey or Delaware commuters are enrolled in the lease-and-park system, there is no reason to believe that their Minicars will not be used in intrastate movement within those states. Fortunately, neither New Jersey nor Delaware seems to assert jurisdiction over a system of driverless vehicles with no fixed routes.

a. New Jersey Public Utility Commission (N.J. PUC). New Jersey law defines a public utility to include anyone who "owns, operates, manages, or controls" an autobus for public use. N.J. Stat. Ann. §48:2-13. An "autobus" is defined as "any motor vehicle...operated over public highways...for the transportation of passengers for hire in intrastate business, notwithstanding such motor vehicles may be used in interstate commerce." N.J. Stat. Ann. §48:4-1. The MTS will "own" a motor vehicle which will be "operated" on public highways by its lessees. But only if the lessee of the vehicle operates it "for hire" does the vehicle become subject to regulation, and the MTS can prohibit such use of its vehicles. In addition, New Jersey distinguishes between those providers of vehicles who do and those who do not retain control. Thus, charter buses are subject to regulation only when they are operated by the owner or lessor, or by his agent. N.J. Stat. Ann. §§48:4-1, 48:4-11. And finally, rent-a-car operations are regulated by New Jersey law as to insurance and liability not with the public utilities, but in a separate chapter entitled "Professions and Occupations." New Jersey Stat. Ann. §§45:21-1 to 13.

Since Minicars do not qualify as autobuses, they are not only exempt from N.J. PUC regulation, but need not obtain permission from New Jersey municipalities before operating within their boundaries. N.J. Stat. Ann. §48:4-3.

b. Delaware Public Utility Commission. Delaware's definition of a public utility more easily excludes the MTS. Anyone "who operates... within the state...any...motor bus (or) taxicab" is a public utility. Del. Code Ann. tit. 26 §101 (Supp. 1968). Although neither motor bus nor taxicab is further defined in the Statute, they are words commonly used by the public to refer to specific types of operations, neither of which includes Minicars. One court defined and distinguished the terms as follows: "The word 'taxicab' has a well-known and definite meaning. Vehicles which operate from a fixed station at which the drivers receive passengers or receive telephone calls directing them where the passengers will be found, and which drive to the destination of their passengers...should not be classified with (motorbuses) which drive back and forth along one street...picking up passengers from the sidewalks..." Frick v. City of Gary, 192 Ind. 76, 135 N.E. 346(1922). See also Yellow Cab Co. v. Pengilly 11 SW2d 560 (Tex. Ct. Civ. App., 1928). In accordance with these distinctions, Delaware, like New Jersey, found it necessary to regulate the insurance of automobile lessors separately from that of public utilities such as taxis and motorbuses. Del. Code Ann. tit. 21 § 2105.

D. Insurance Requirements: Property Loss and Personal Injury  
Liabilities of the MTS

1. Minimum Insurance Requirements

The obligations and liabilities of the MTS under the financial responsibility and minimum insurance laws of Pennsylvania, New Jersey and Delaware are discussed fully in a separate memorandum [T-22]. While the laws of each state differ as to the precise amount of coverage, and the procedures which are prescribed for securing appropriate approval and qualification to operate within the state, they should not affect the decision as to the type and amount of coverage MTS should carry. As a practical matter, MTS should carry more insurance than is prescribed by these laws and should secure full coverage not only for its own acts of negligence but also for those of all its lessees. Although our conclusions must be verified through actual discussions with insurance carriers, we believe that reliance by the MTS on the lessee's other car coverage would be extremely unwise.

2. Potential Liabilities of the MTS: Private Unregulated System

a. Negligent Entrustment. The general rule in Pennsylvania, New Jersey and Delaware, as in most states, is that an owner who entrusts his car to another is not liable per se for loss and injuries caused by the negligent or wanton acts of that other person, unless his decision to entrust the car is itself an act of negligence towards the person suffering the loss or injury.\*

Special common law principles exist which impose liability on the owner where the negligent operator is his agent or servant, or where the owner is present in the automobile when the accident occurs; but the MTS, when renting to paying customers, will not fall into either of these categories. A rule that is more relevant to the MTS is one which imposes liability upon the owner if he negligently entrusts his automobile to an incompetent driver who injures a third person as a result of that incompetence (which may be a physical disability, intoxication or alcoholism, ignorance as to how to drive a car, a history of reckless driving, etc.). Clearly, if the MTS distributes its charge cards to the public indiscriminately and unquestioningly, the possibility exists that they will fall into the hands of such incompetents. What constitutes a negligent entrustment, and what amount of care the MTS must exercise in selecting its customers in order to avoid being held for negligence?

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\*See cases collected in [T-22, p. 19], where some special statutory provisions applicable in Delaware and New York are also discussed.

Traditionally, the courts have required that the owner have some knowledge of the borrower's incompetence at the time the automobile is entrusted to him before negligence can be imputed to the owner. At first glance this prerequisite to negligence absolves the MTS of all fault. If the MTS does not upon an application request information about an applicant's disabilities, and if it does not post a person or machine that can observe his physical condition at the time and place a customer checks out his car, it will have no knowledge of any disabilities. Can the MTS, by carefully closing its eyes and ears, avoid liability for the incompetent?

The courts have expanded the meaning of "knowledge" in a variety of ways. The leading Pennsylvania case holds that evidence of the borrower's incompetence is relevant "(if) the record (shows) any circumstances sufficient to acquaint a reasonably prudent person of some incompetence on the part of (the borrower)...." Chamberlain v. Riddle, 155 Pa. Super. 507, 511, 38 A.2d 521, 523 (1944); Littles v. Avis Rent-a-Car System, 433 Pa. 72, 248 A.2d 837 (1969). New Jersey courts have also referred to the principle imposing liability on the owner when he "knows or ought reasonably to anticipate" that injury will follow from entrusting his car to another. Mead v. Wiley Methodist Episcopal Church, 4 N.J. 200, 206, 72 A.2d 183, 186 (1950). What burdens do such phrases place on an owner lending his car? To date, however, courts and commentators appear to agree that the owner need not concern himself with the competence of a borrower unless some facts or circumstances are brought to the owner's attention which would make a reasonable man suspect that something is amiss. In the latter case, if the owner fails to investigate further he may be found negligent. For example, if the owner has just witnessed his friend quaff several drinks, he should not immediately hand him the keys to his car. Petermann v. Gary, 49 So.2d 828 (Miss., 1951); Dixie Drive-It-Yourself System Jackson Co. v. Matthews, 54 So. 2d 263 (Miss., 1951). Similarly if the owner has heard (or if everyone else in the neighborhood has heard) of his friend's history of reckless driving, he should not without more lend a car to him. Guedon v. Rooney, 87 P.2d 209 (Or., 1939). On the other hand, if a person who looks old enough to have a license asks to use the car, the owner need not inquire as to whether he has a license. Chamberlain v. Riddle, *supra*. Apparently, all presumptions are in favor of the competence of the person who asks to use an automobile; one who hires a vehicle, it is said, impliedly represents himself as being competent to operate it. Eklof v. Waterston, 285 P. 201 (Or., 1930).

Although these cases penalize the owner who has observed a condition in the driver which should have put the owner on notice of his incompetence, they do not go so far as to impose an affirmative obligation on the owner to make the observation in the first place. There is no assurance, however, that the attitude of the courts will remain the same when faced with a computerized system such as is proposed for the MTS.

The rules about negligent entrustment were developed before the age of the computer, and involved certain typical situations -- the father who lends his car to a member of the family, the man who lends his car to a friend, or the traditional rent-a-car (or horse and buggy) agency. These situations all have one thing in common: a face-to-face encounter between borrower and lender, immediately or shortly before the borrower takes the car.\* Now that it has become possible to entrust a car through the medium of a machine, can the owner escape liability by simply failing to establish a system through which evidence of incompetence that would be "apparent" to anyone present is communicated to the decision maker?

A significant dissenting opinion written by Justice Roberts in Littles v. Avis Rent-a-car System, 433 Pa. 72, 248 A. 2d 837 (1969), as well as a number of earlier decisions to be found in Louisiana and Texas, strongly indicate that the old doctrine requiring knowledge, actual or imputed from actual observation, of the driver's incompetence, will give away in favor of a requirement that the owner take affirmative steps to acquaint himself with the driver's condition at the time when the car is entrusted to him. In the case of MTS, this means at each time when the car is withdrawn from the terminal. These cases are discussed at some length in [T-22, pp. 25-32]. If the law does develop in this direction, as we believe it will, the next phase, posing difficult questions for the MTS, may involve a requirement that the MTS react to the driver's history (at least so much as is or could readily be stored in the MTS data banks) and that it monitor his performance after the car is withdrawn from the terminal. These questions are discussed in [T-22, pp. 28-32]. Also discussed in that memorandum are the following special situations (only the conclusions being repeated here):

b. Liability to Guest Passengers for Negligent Entrustment.

Where, as in Pennsylvania and New Jersey, there is no "guest passenger" statute, the MTS will be liable to guest passengers on the same basis and to the same extent as it will be liable to others. In states such as Delaware, which have a "guest passenger" statute, the MTS will probably not be liable to guests for negligent entrustment of the car to an incompetent driver, because these statutes require some willful and wanton act on the part of the driver and this requirement has been construed to extend to the owner (in cases involving defective vehicles).

c. Liability if Someone other than a Card Holder Operates a Minicar.

(i) If the Card-Holder Lends his Card to Another. Two cases are possible under this heading: one is where the card-holder checks out the car

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\* The only case failing such an encounter involved permission being given over the telephone. There was, however, some communication between the parties, and the borrower was not a stranger to the lender. Entrustment was held not to be negligent. Ellsworth v. Ludwig, 223 N.E. 2d 764 (Ind., 1967).

and then entrusts the car to another; the other is where the card-holder entrusts the card to another and that person checks out the car. In the first case, our conclusions are that if the MTS would not be liable for injuries or loss caused by the card-holder (on the principle of negligent entrustment discussed above), it will not be liable for injuries or loss caused by a person to whom the card-holder entrusts his car. Just as the law may change for the MTS on the question of negligent entrustment so it may change on this question also. The possibility that the car may find its way into the hands of an incompetent driver does not hinge on the competence of the driver to whom the car is entrusted but on his responsibility for the car and card. It is not unlikely, therefore, that the courts may hold MTS liable if it fails to revoke the card of a competent driver who, to its knowledge, has frequently loaned the car to unauthorized persons. This information is most likely to reach MTS through the second case, if it has any checking procedure for determining whether the card belongs to the person who is withdrawing the car at the terminal. Our conclusion in the second case is that MTS will not, as the law now stands, be liable for injuries and loss occasioned by an unauthorized driver merely because it has failed to devise a full-proof procedure for matching the card with its authorized user. To have no procedure at all, however, not even a visual scanning of the person for obvious doubts as to his condition or authority to operate the vehicle will undoubtedly result in liability. We believe that the courts will require MTS to go as far in this direction as is reasonably feasible--possibly to the extent of requiring some additional form of recognition.

(ii) Lost or Stolen Cards. What has been said above is equally applicable to injuries caused by a thief or finder of the card.

d. Liability for Renting a Defective Vehicle. The fact that MTS plans to use a unique car and to service it with mobile, fully automated, equipment may as a practical matter impose a greater duty to discover defects on MTS than on typical rent-a-car operators. Courts and juries respond more readily to differences in an owner's ability to discover defects than to any argument of absolute equality of obligation.

### 3. Potential Liabilities: Private Regulated System

If the MTS is classified as a common carrier (see discussion, pp.210-212 supra) under the jurisdiction of a Public Utilities Commission, any doubts expressed as to its duties and liability in particular instances discussed above are likely to be resolved against it simply because, traditionally, common carriers are held to a higher standard of care than private, unregulated operators. Otherwise, its duties and liability with regard to persons and property will be governed by the same principles as those discussed above.

#### 4. Potential Liabilities: SEPTA Operated System

While SEPTA operated systems are not subject to PUC regulation (except outside the "metropolitan area", see pp. 208-209 supra), all systems operated by SEPTA are likely to be classified as common carriers for purposes of liability. Indeed, to the extent that MTS would not be properly classified as a common carrier, to that extent there is some doubt as to whether SEPTA has authority to operate it (see p. 209 supra). Accordingly, if SEPTA has authority to and does operate MTS, its duty of care and liabilities will be governed by the principles discussed in the preceding Section.

#### E. Potential Criminal and Quasi-Criminal Liabilities of the MTS and its Officers

The problem covered by this title are fully discussed in [T-23] . Five offenses provided under varying combinations of Pennsylvania, New Jersey and Delaware laws have been identified and are discussed in that reference: (i) permitting an unregistered vehicle to be on the public highways; (ii) equipment violations; (iii) permitting an intoxicated person to operate a Minicar; (iv) permitting a minor or anyone without a valid license to operate a Minicar; and (v) failing to keep records of vehicles leased. Although all of these require some care on the part of MTS if it is to meet the varying procedures and requirements in each of the three states, the offenses which pose the most difficulty in this respect are (iii) and (iv).

Typically, the penalties for permitting intoxicated persons, minors or unlicensed drivers to operate a vehicle may be incurred by the owner or person who is in control of the vehicle at the time without regard to his knowledge or lack of knowledge that the operator is disqualified. Although the courts have been loath to impose the penalties on owners who are entirely blameless in the matter, a large commercial operation such as MTS cannot afford to rely on this defense unless it can satisfy the courts that it has done everything reasonably possible to avoid violations. While the monetary penalties are generally insignificant, revocation of licenses can follow and an extensive rash of violations may persuade a court to impose jail sentences on the persons directly to blame.

All of this adds up to the conclusion that MTS must establish procedures to prevent persons who are disqualified from being able to take the cars at its terminals. Ordinarily, once the car is taken by a qualified person, MTS will not be penalized for his letting a disqualified person operate the vehicle thereafter, since the penalty falls on the person who is in control of the vehicle at the time. Possibly, the incidence of the penalty might shift to MTS if there are readily available methods for preventing subsequent transfers to disqualified persons. At the moment, this is highly unlikely.

## F. Conclusions

The work so far completed permits us to draw the following general conclusions limited to the tri-state area of Pennsylvania, New Jersey and Delaware:

### 1. Government Control of the MTS

If SEPTA operates the MTS, no state or federal regulatory agency aside from SEPTA itself has jurisdiction. If the MTS is privately owned, the Pennsylvania Public Utility Commission may have jurisdiction; and since there is uncertainty, a private operator would be well advised to apply to the Commission before starting operations.

### 2. Insurance Requirements: Property Loss and Personal Injury Liabilities of the MTS

The MTS will have to insure its customers as well as itself in order to satisfy the Pennsylvania, New Jersey and Delaware financial responsibility requirements. For if its customers are not liberally insured, in actions arising out of the negligence of a customer the juries will sympathize with the injured plaintiff, and seeing a large organization which can spread the cost of liability, will make the MTS jointly liable with the customer. Such joint liability can be imposed on the MTS when it has negligently entrusted its vehicle to an incompetent, and possibly when it has failed to prevent withdrawal by an unauthorized person at its terminals. The insurance carrier who insures MTS for its own liability is bound to consider the fact that judgments against large corporations tend to run considerably higher than against individuals. It seems likely, therefore, that the carrier will demand as a condition of coverage that MTS take every reasonable precaution to avoid judgments against itself. Thus the carrier may demand that MTS establish procedures at its terminals which are reasonably capable of determining the competence of the customer before he withdraws the vehicle--possibly, even, procedures capable of determining whether the user is an authorized card holder.

In addition, the MTS can be liable individually if it provides a defective vehicle to a competent driver. The inspection procedures which the MTS utilizes therefore must be thorough and frequent. If the MTS is designated as a common carrier or is operated by SEPTA, these procedures must allow for a few mistakes, as the standard of care which the courts apply to a common carrier is higher than that applied to an unregulated rent-a-car business.



### 3. Potential Criminal and Quasi-Criminal Liabilities of the MTS and its Officers

Five offenses provided under varying combinations of Pennsylvania, New Jersey and Delaware law have been identified as having special applicability to the MTS. Regarding these offenses as a group, it is more likely that the MTS can be convicted of violating them as a corporation than that individual MTS officers can be reached; it is more likely that the MTS will be tried for offenses prescribed by Pennsylvania law than those prescribed by Delaware or New Jersey law (unless rental terminals are established in those states); it is unlikely that any penalties besides relatively small fines will be imposed for any violations; and it is unlikely that any convictions will take place if the MTS is careful to screen its vehicles and customers each time they exit from an MTS terminal.

In determining whether to omit expensive or inconvenient precautions at the terminals and risk the consequences, however, the MTS should be concerned about criminal and quasi-criminal liability arising out of its operations. Although the fines may never be larger than several hundred dollars, they may be numerous; and a contract which attempts to insure against such liability is void as against public policy and therefore will not be enforced by the courts. Krauss v. Allstate Insurance Co., 258 F. Supp. 407 (W.D. Pa. 1966), aff'd, 379 F.2d 443 (1967); Esmond v. Liscio, 209 Pa. Super. 206, 224 A.2d 793 (1966). Numerous violations may lead to revocation of MTS licenses. In addition, the possibility of imprisonment for individual MTS officers, though small, is not inconsiderable, especially if there are numerous instances of Minicars being entrusted to intoxicated persons who cause severe personal and property damage. And needless to add, public confidence in, and acceptance of, the MTS will be greatly undermined by even a few minor criminal proceedings against the System.

## Technical Supplement S-IX

### IMPACT OF VEHICLE SIZE ON TRAFFIC FLOW

#### A. Introduction

A simulation that was correlated with traffic survey data was performed to obtain additional information on the effect of Minicars upon urban high density traffic. The simulation was based on a linear car-following model in single line traffic; it was performed on a digital computer, utilizing a modified version of a program previously developed and reported in [R-3].

From the traffic survey of the Philadelphia CBD, reported in Technical Supplement XI, data on Chestnut Street between the intersections of 21st and 7th Streets (see Figure SIX-1) were selected for simulation. The constants in the computer program were calibrated so that the results of the simulation agreed with the block lengths and traffic signal timings. Runs were then made to simulate different traffic compositions with respect to vehicle size.

Due to this procedure, the results of this simulation represent a more accurate picture of the effect of Minicars upon urban high density traffic than the results previously obtained from simulation, as reported in [P-8].

#### B. The Simulation Model

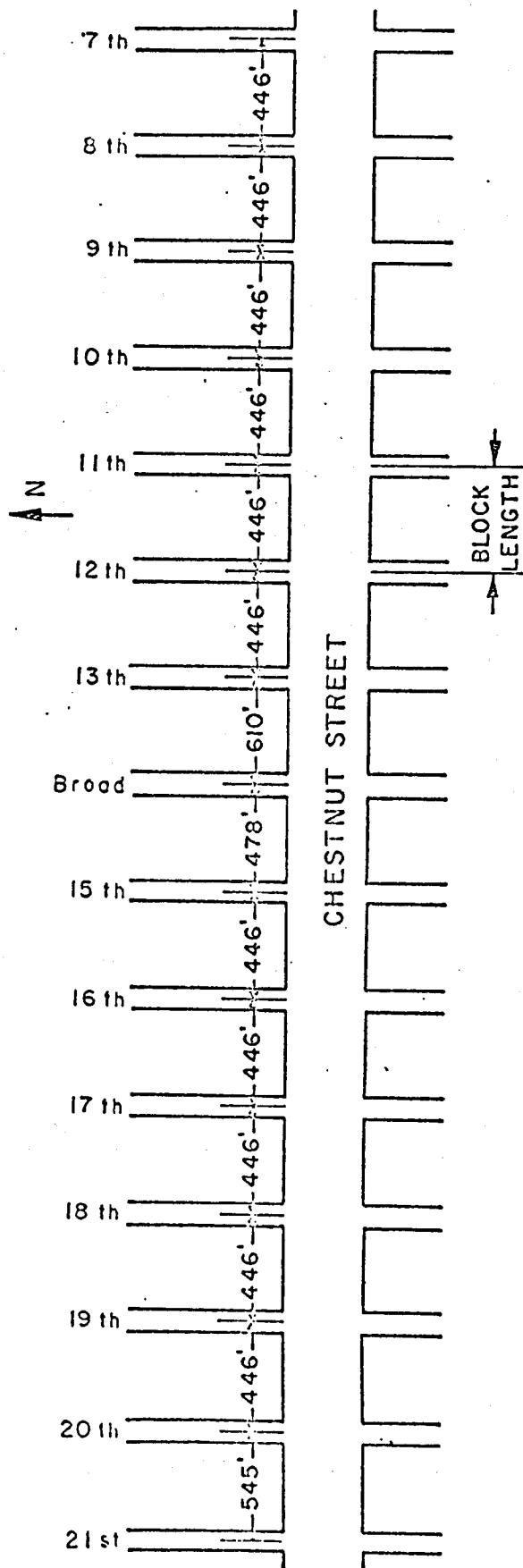
The car-following model used is based upon the general car-following model, formulated by Gazis, Herman and Rothery [B-7]:

$$\ddot{X}_{n+1}(t+T) = \beta \frac{\dot{X}_{n+1}^m(t+T)}{[X_n(t) - X_{n+1}(t+T)]^L} \left[ \dot{X}_n(t) - \dot{X}_{n+1}(t) \right]$$

where

$$\ddot{X} = \frac{d\dot{X}}{dt} \quad \text{and} \quad \dot{X} = \frac{dX}{dt} ;$$

$X_n(t)$ ,  $X_n(t+T)$  - position of the  $n^{\text{th}}$  vehicle at time  $t$  and  $(t+T)$ , respectively;



Number of Vehicles Queued in Each Block

A.M.	5	5	5	5	5	5	5	5	5	4	0	0	0	0
NOON	5	5	5	10	17	18	24	9	8	17	0	0	0	0
P.M.	3	5	5	5	7	10	12	6	8	10	5	4	0	0

FIGURE SIX-1. SURVEYED STREET AND NUMBER OF VEHICLES QUEUED

$X_{n+1}(t), X_{n+1}(t + T)$  - position of the  $(n + 1)^{th}$  vehicle at time  $t$  and  $(t + T)$ , respectively;

$T$  - driver reaction time;

$\beta, m, l$  - constants.

In order to simulate the linear car-following situation, constants in the above equations were determined to be  $m = 0, l = 1, \beta = 30$ . This enabled simulation of the acceleration or deceleration of each vehicle traveling along Chestnut Street.

Chestnut Street was divided between the intersections of 21st and 7th Streets into 14 sections. Each section starts at the east edge of the intersection and ends at the east edge of the next intersection. The program calculates the average time and velocity of the vehicles crossing a particular section and also counts the traffic flow at the reference point centerline of the Broad Street intersection. The number of cars initially queued at each intersection was set by using previously calculated statistical data.

The computer program uses the McClenahan and Simkowitz model [P-8] with some modifications and two additional subroutines. The simulation takes into account the varying traffic flow rates at the peak periods during the morning, noon and evening rush hours by adjusting the parameter  $\beta$ . The flexibility of the program permitted tailoring the simulation model specifically for these periods by adjusting not only the peak flow rates, but the percentage of standard length cars, buses and Minicars.

The computer program calculates the driver's response to a continuous stream of traffic stimuli, such as whether or not it is possible to cross the intersection on a yellow light, whether the car ahead is decelerating or accelerating, whether there is a sudden obstruction in the road, etc. The standard high speed printer of the IBM 360/75 is used for graphic display by scaling the 131 spaces per line to represent approximately the 2700 feet of Chestnut Street used in the simulation and denotes each car as a numeral, 0 to 9. Each line displays the actual position of car "n" at some time  $t_i$ . Thus, one can easily see the traffic pattern, signal phase, and general flow of traffic by scanning down the computer output page.

### C. Results

As previously described, the three periods, A. M. peak, Noon and P.M. peak hours yield three distinct sets of results. Each set consists of the data resulting from different traffic composition (regular length cars and Minicars) in 25 percent increments.

The average speed (in feet per second) obtained by a simulation run for 100% conventional car traffic composition compared with actual surveyed traffic speeds was as follows:

	<u>A.M. Peak</u>	<u>Noon</u>	<u>P.M. Peak</u>
Simulation	15.66	6.02	10.11
Survey	16.02	5.88	10.04

The results of the simulation clearly show that the model applied is acceptable and reliable. The deviations, defined as:

$$\text{DEVIATION} = \frac{\text{Ave. Simulated Speed} - \text{Ave. Surveyed Speed}}{\text{Ave. Surveyed Speed}} \times 100\%$$

have the following values: 2.33% for A.M. peak, 2.43% for Noon, 2.67% for P.M. peak.

All sets of data are given in Table SIX-1, including the percentage increase in speed and flow of vehicles per hour with respect to conventional car data (100% conventional, 0% Minicars). Average speeds (V) and/or flow of vehicles per hour vs. different percentages of Minicars are plotted in Figures SIX-2 and SIX-3 respectively. The graphs show convincingly that the introduction of Minicars into the traffic stream increases flow rates and average speed of traffic. Specifically, traffic consisting of only Minicars shows a 35.23% increase in average speed and a 28.94% increase in flow over traffic with conventional cars only. For traffic composition with 50% Minicars corresponding increases are 14.0% in speed and 7.67% in flow.

It can be seen from the results that the percentage increase in average speed and in flow due to shorter vehicle length depends on the extent of congestion. The greatest increase takes place when congestion is the greatest.

#### D. Calculation of Passenger Car Units

The p.c.u. (passenger car unit) of a vehicle is defined as the ratio of transportation requirements (area taken and impedance created to other vehicles) of that vehicle to the transportation requirements of a conventional passenger car. In other words, if the maximum flow of cars which is limited by the physical size of the street is X vehicles per hour, and if maximum flow of another vehicle type (e.g., buses or trucks) is Y vehicles per hour, the p.c.u. for the buses will be X/Y (see [R-5, p. V-50]).

TABLE SIX - 1. SIMULATION RESULTS

Time Period	Parameter	Traffic Composition (% 20-ft. Cars) - (% 10-ft. Cars)				
		100 - 0	75 - 25	50 - 50	25 - 75	0 - 100
A.M.  Peak	V	15.66	16.69	17.13	17.53	17.84
	$\Delta V$	0.0	1.02	1.46	1.87	2.18
	$(\Delta V/V_o) 100\%$	0.00	6.54	9.34	11.92	13.92
	Q	618	630	663	686	720
	$\Delta Q$	0	12	45	68	102
	$(\Delta Q/Q_o) 100\%$	0.00	1.94	7.28	11.0	16.50
NOON	V	6.02	6.24	6.86	7.57	8.14
	$\Delta V$	0.0	0.22	0.84	1.55	2.12
	$(\Delta V/V_o) 100\%$	0.00	3.63	14.00	25.75	35.23
	Q	456	456	491	526	588
	$\Delta Q$	0	0	35	70	132
	$(\Delta Q/Q_o) 100\%$	0.00	0.00	7.67	15.35	28.94
P.M.  Peak	V	10.11	10.78	11.23	11.96	12.23
	$\Delta V$	0.0	0.67	1.12	1.86	2.13
	$(\Delta V/V_o) 100\%$	0.00	6.67	11.08	18.35	21.05
	Q	500	535	544	579	597
	$\Delta Q$	0	35	44	79	97
	$(\Delta Q/Q_o) 100\%$	0.00	7.0	8.8	15.8	19.4

V - Average Speed [ft/sec]

$V_o$  - Average Speed for 100% standard cars [ft/sec]

$\Delta V = V - V_o$

Q - Traffic flow [veh/hr]

$Q_o$  - Traffic flow for 100% standard cars [veh/hr]

$\Delta Q = Q - Q_o$

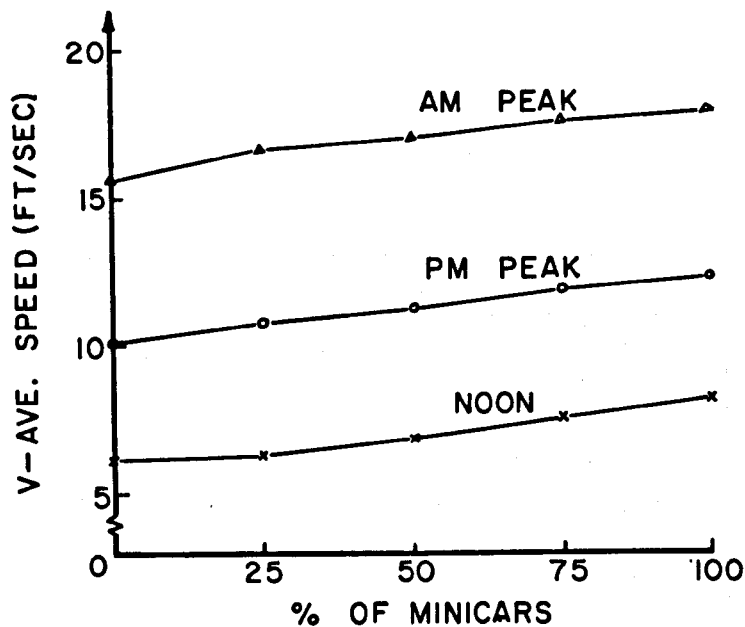


FIGURE SIX-2  
SPEED FOR DIFFERENT  
TRAFFIC COMPOSITIONS

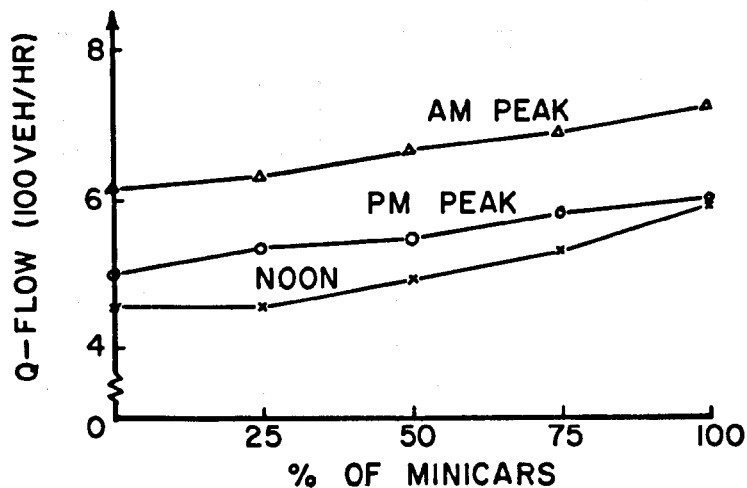


FIGURE SIX-3  
FLOW FOR DIFFERENT  
TRAFFIC COMPOSITIONS

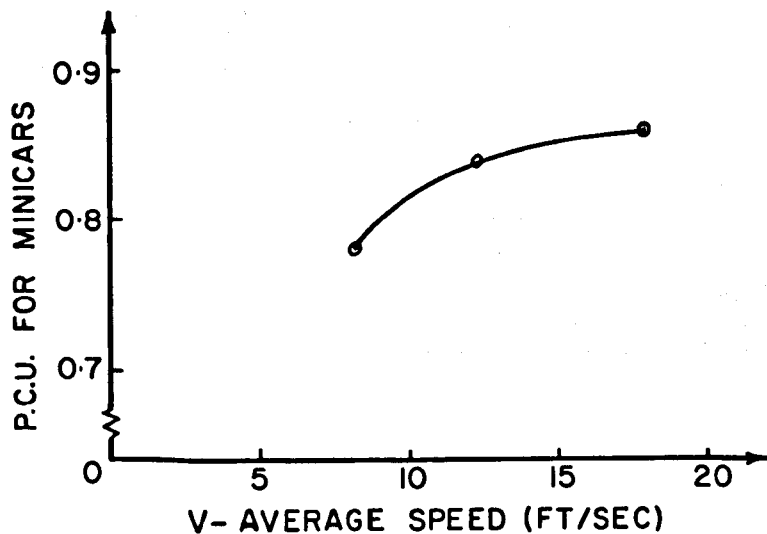


FIGURE SIX-4  
MINICAR P.C. U. VALUES  
FOR DIFFERENT TRAFFIC  
SPEEDS

Based on this definition of p.c.u., it was calculated that at an average velocity of 17.84 fps (or 12.1 mph), the p.c.u. for Minicars is 0.86; at speed of 12.23 fps (or 8.3 mph), the p.c.u. for Minicars is 0.84, and at a speed of 8.14 fps (or 5.5 mph), the p.c.u. is 0.78. These data are shown in Figure SIX-4.

#### E. Conclusions

This simulation was performed in order to obtain more accurate and realistic results as compared to the simulation performed in Phase I, [R-5]. Although the differences between the results of the two simulations are not great, the fact that extensive survey data and an updated computer program were utilized, coupled with excellent results of tests of correlation between simulation results and survey data, tends to increase credibility to the results of these analyses.



Technical Supplement S-X  
CONGESTION AND QUEUING

Studies of the flow of traffic with different compositions of vehicles (see Technical Supplement S-IX) have shown that Minicars would increase the flow by a percentage which varies inversely with speed. The increase of flow under highly congested conditions would be quite significant (in the order of 50 percent); improvement decreases with speed and becomes quite negligible at the speeds of free-flowing traffic on freeways (50-60 mph). The difference between the flow of Minicars and the flow of standard automobiles at different speeds of traffic can be schematically presented on a diagram of flow change,  $\Delta q$  (percentage increase with respect to the flow without Minicars), as a function of speed,  $v$ , shown in Figure SX-1.

This Supplement analyzes, based on these findings, the impact Minicars would have on traffic flow and congestion in some practical situations.

The example which will be illustrated here is the convergence of several highways. Suppose that several highways merge and the total number of lanes is reduced in that section, so that a "bottleneck" in highway capacity is created. Although such situations are considered undesirable in highway design, they sometimes cannot be avoided. A typical case of this is the convergence of highways at bridges and tunnels. Excellent examples of such situations are several bridges from Virginia into Washington across the Potomac River; the George Washington Bridge and Hudson River Tunnels in New York City; and the Golden Gate and Bay Bridges in San Francisco.

To obtain some quantitative measures of the potential impact of Minicars, let us assume that a freeway with three lanes per direction is approaching the bridge; two other highways with two lanes per direction each merge with this highway and lead into a bridge with three lanes per direction, as shown in Figure SX-2.

It is assumed that the capacity of these highways and the bridge is 1500 vehicles/hour/lane and that the traffic fluctuations in time are typical for a radial facility with commuter traffic. The fluctuations for the A. M. peak period have been based on the diagram from the Traffic Engineering Handbook (1965 Edition, p. 154), assuming an average flow of 900 vph/lane.

Figure SX-4 depicts this total traffic volume approaching the bridge during the A. M. peak period. Since the highest volumes using

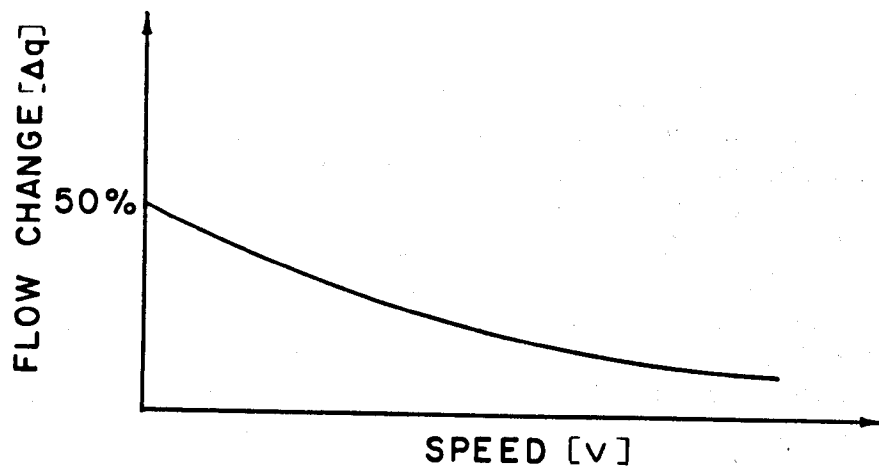


FIGURE SX-1. FLOW CHANGE AS FUNCTION OF SPEED

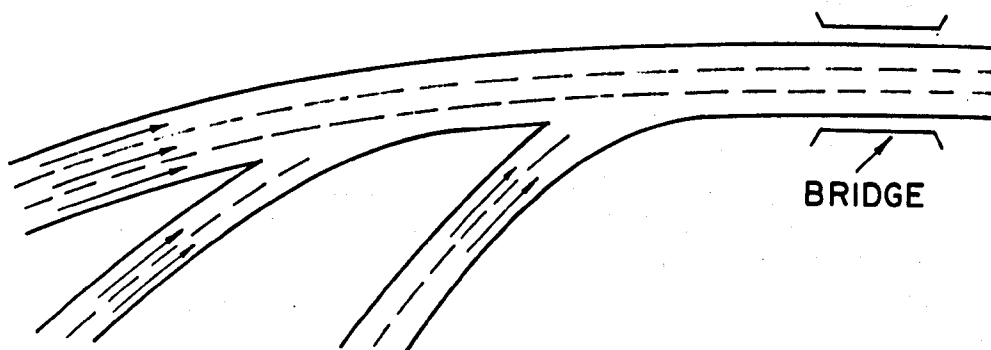


FIGURE SX-2. TRAFFIC BOTTLENECK (SCHEMATIC)

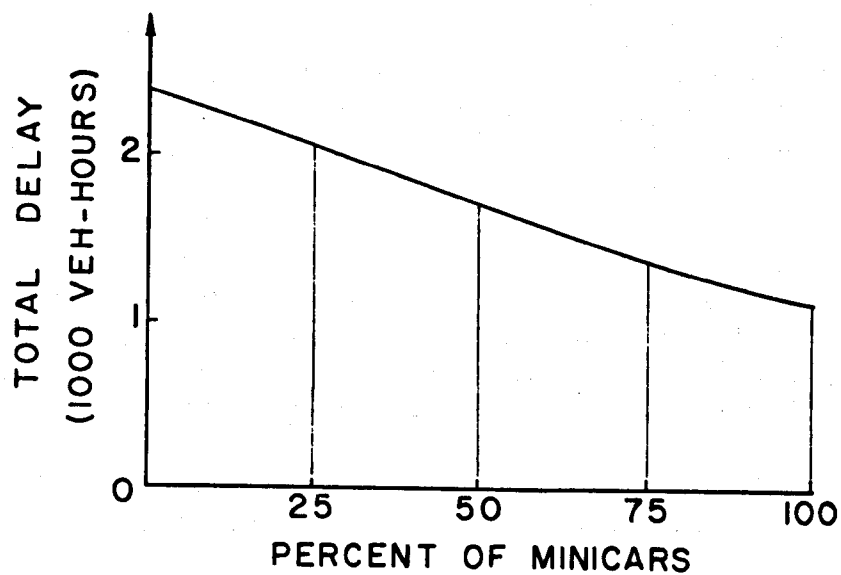


FIGURE SX-3. VEHICLE DELAY AT LIMITED CAPACITY LOCATIONS  
AS A FUNCTION OF PERCENT OF MINICARS

the seven approach lanes exceed the capacity of the bridge, a portion of the peak hour traffic will be delayed until it can pass "under the capacity line," as shown on the diagram.

This traffic flow can be presented in a different form on a diagram of the cumulative flow (cumulative number of vehicles) as a function of time, as shown in Figure SX-5. This diagram, actually representing the integral of the traffic flow diagram, is plotted directly below the latter one. The slope of the curve represents the rate of flow. When the flow increasing toward the maximum reaches the slope corresponding to the bridge capacity, the rate of vehicles passing across the bridge remains at that slope, so that an area is created between the "input" flow to the bridge and "output" flow from the bridge. The height of this area at any point in time represents the length of the queue backing up from the bridge. The total area represents vehicle hours lost due to the back-up.

A computer simulation of traffic flow under conditions similar to the ones assumed in this example indicates that at low, congested speeds of traffic flow Minicars have approximately 15% higher flow than standard automobiles. From the two diagrams it can be seen that in the Minicar case the back-up will start later and the queue will grow more slowly since the discharge rate will be 15% higher than with standard automobiles. The lower diagram thus shows the differences in the total time lost, length of queue and its duration for the two cases: one with all standard automobiles, and the other with all Minicars, respectively.

For an alternate presentation of the impact of Minicars on traffic conditions, in regard to user time, two additional diagrams have been developed for the same example.

Figure SX-3 shows the total time of delay due to the backup (in vehicle-hours) as a function of the percent of Minicars in the traffic flow. The delay decreases, with the introduction of additional Minicars, at an approximately constant rate.

The data in this diagram indicate that the total delay time would decrease from 2375 vehicle hours (or an average of 11.7 minutes per delayed vehicle) for the flow of standard automobiles to 1695 vehicle hours (or 8.3 minutes per delayed vehicle) for 50% of the traffic being Minicars, and finally to 1125 vehicle hours (or 5.5 minutes per delayed vehicle) for all Minicars.

The second diagram (Figure SX-6) shows the behavior of the seven-lane queue through time for different traffic compositions. The impact of the proportion of Minicars on the duration of the queue and on its maximum value is obvious in the diagram. The length of the queue has been expressed in lane-feet to show the impact quite realistically. For

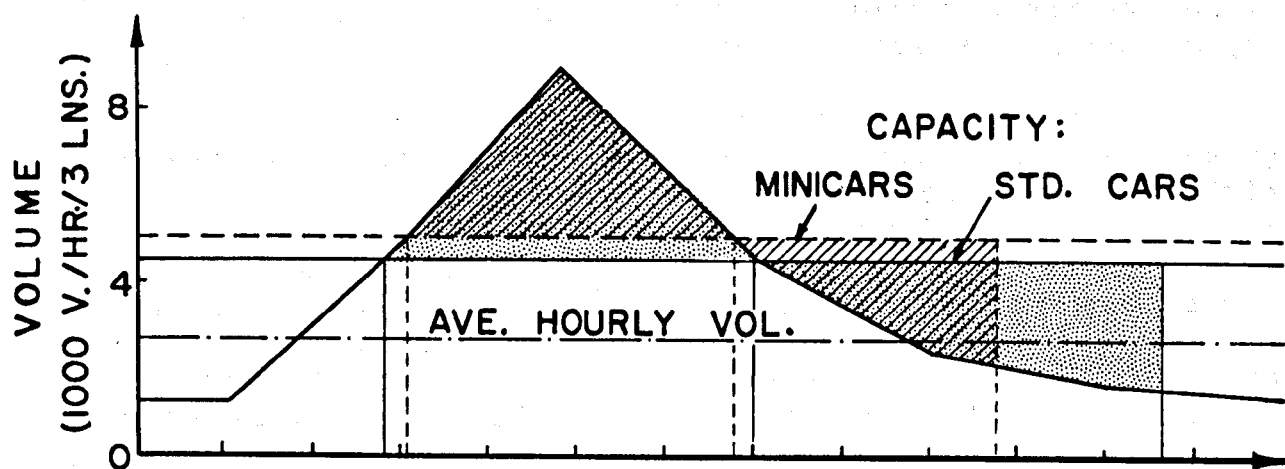


FIGURE SX-4. TRAFFIC FLOW VARIATIONS

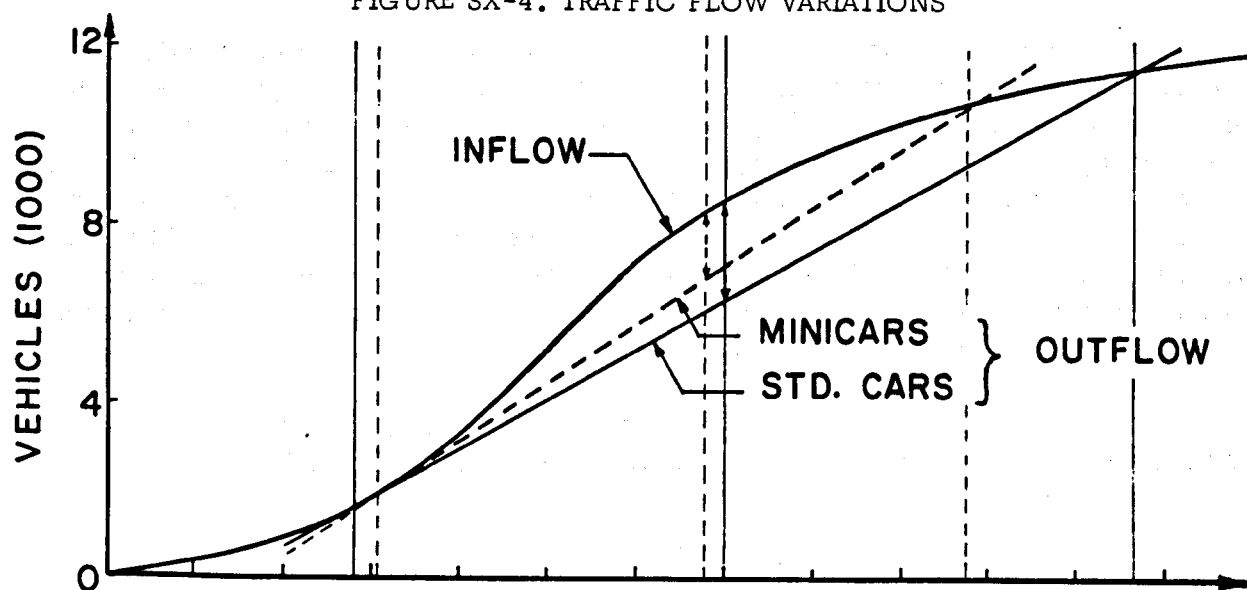


FIGURE SX-5. CUMULATIVE DIAGRAM OF TRAFFIC FLOW

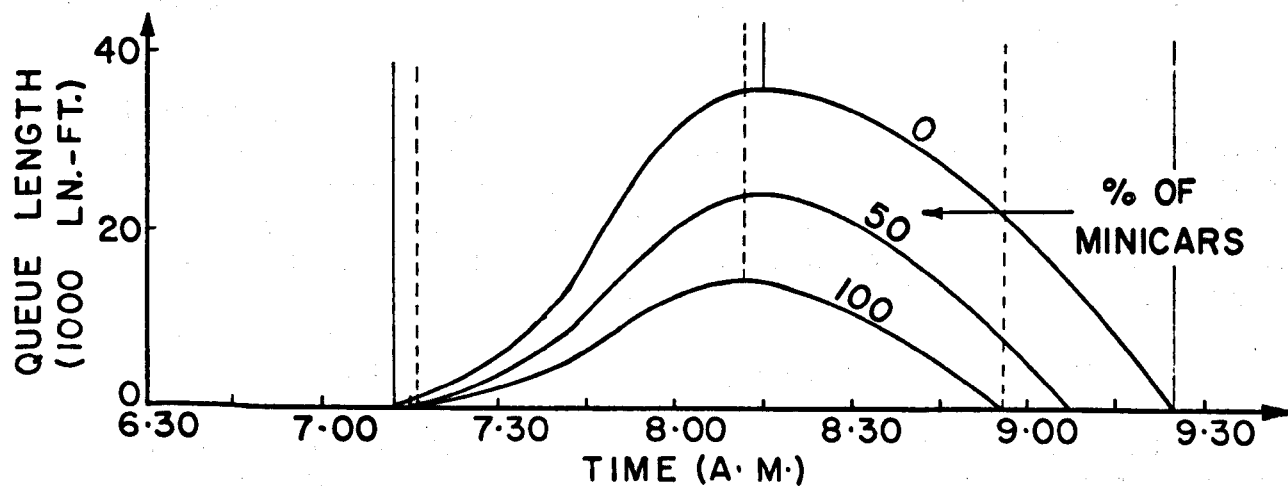


FIGURE SX-6. QUEUE FORMATION AND DESCRIPTION FOR DIFFERENT PERCENTAGES OF MINICARS

this example, if a queue at the bridge reaches a maximum length of 5,400 feet per approach lane for standard cars, then by substituting 25 or 50 percent of the vehicles with Minicars, the maximum queue would become 4,400 and 3,500 feet long on each approach lane, respectively.

The main conclusion of this analysis is that the impact of shorter vehicles on traffic at such critical locations as bridges and tunnels where traffic is presently seriously congested would be very significant. The expected increase of the flow rate of 7.5% (50% Minicars) would, in a situation as presented here, reduce total delay by 29 percent, or an equivalent of 680 vehicle hours for a single peak period. The maximum queue length would be reduced by 35% or by 1900 feet per approach lane.

In some cases this impact of Minicars may be in the long run somewhat different than the above analysis indicates since improved traffic conditions usually result in additional generation of traffic. The additional vehicles on the approaching highways would tend to again increase queuing and delays, thus seemingly offsetting the positive impact of Minicars on traffic congestion. The fact remains, however, that this would not offset all benefits from introduction of Minicars. Even if the delay of traffic would return to the same level as before, a greater number of vehicles would be accommodated by the same highway facilities. The result of such changes is equivalent to that of constructing new highways: despite new traffic generation, enlargement of such facilities is desirable unless it results in other significant losses (e.g. land taking, environmental impact, diversion from transit). Benefits due to Minicars would be obtained through improved utilization of the existing facilities and therefore be more desirable than construction of new ones. As an illustration of the magnitude of the savings due to reduced need for new facilities as major bridges and tunnels can be as high as \$5 - 10 million per lane.\*

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\* In the extreme cases this figure may be much higher. For example, the Port of New York Authority estimates that the cost of a lane in tunnels under the Hudson River is in the vicinity of \$50 million.

## Technical Supplement S-XI

### TRAFFIC CONDITIONS IN THE PHILADELPHIA CBD

#### A. Introduction

Since the study of the impact of Minicars on urban traffic had to focus on detailed traffic conditions on local urban streets, including such factors as traffic speeds, congestion and causes for congestion, parking problems, etc., it was necessary to have detailed data about all these conditions. These data proved to be more difficult to obtain than the data on transportation at the regional level. Consequently, the information obtained from a number of agencies had to be supplemented by a field study by the Transportation Engineering group on this Project.

##### 1. Purpose of Study

The objective of this study was to derive a quantitative and qualitative picture of traffic conditions in the Philadelphia CBD; an attempt was also made to define a "level of service index" for urban traffic and to use it for evaluation of traffic conditions in Philadelphia. The purpose of this analysis was three-fold:

- Determine parametric data for use as inputs into a simulation model of traffic flow;
- Estimate the impact of Minicars by analyzing the impact of vehicle size on traffic conditions;
- Obtain data required for planning (location and design) of terminals for the eventual experimental Minicar Transit System.

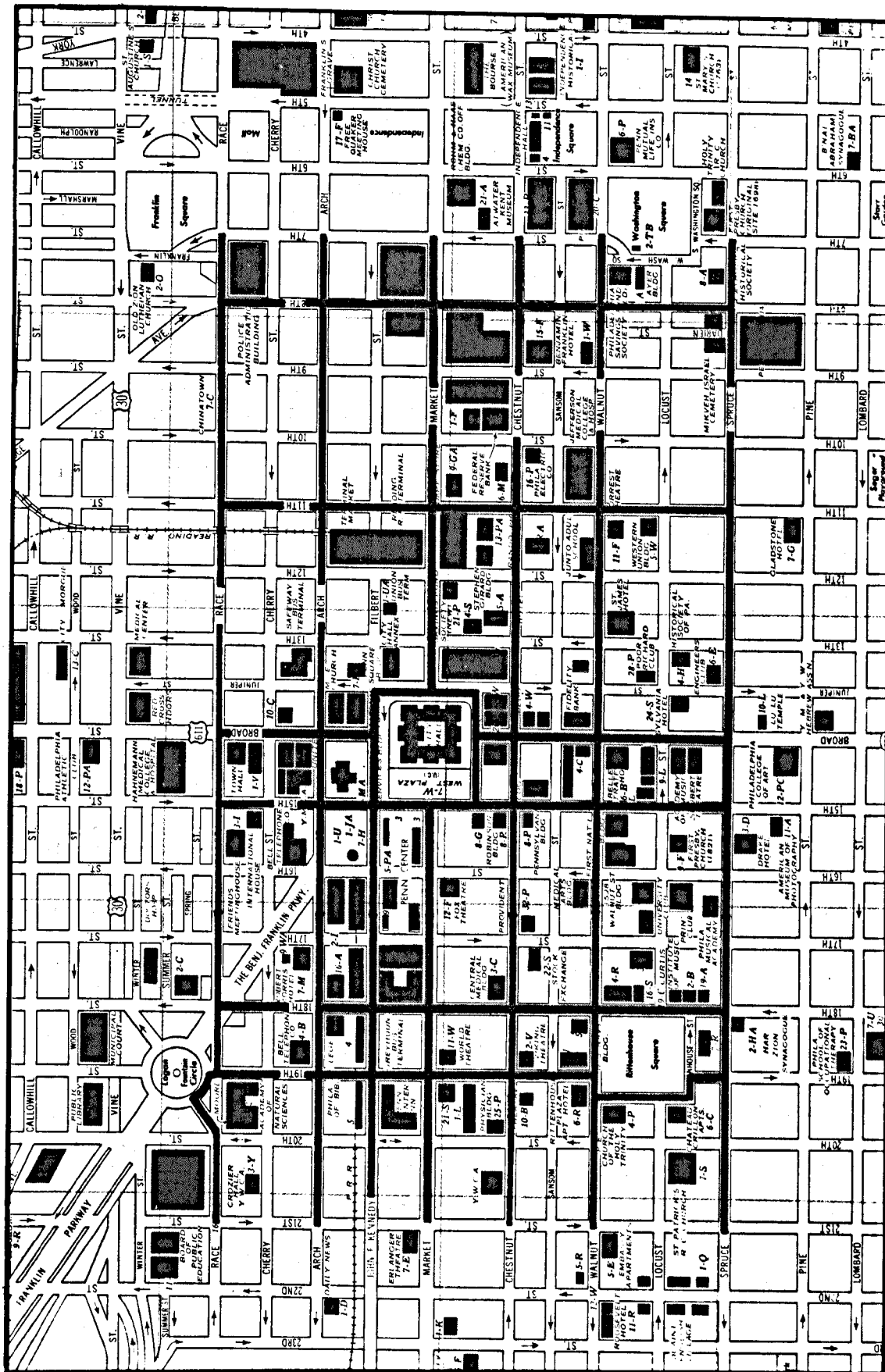
##### 2. Method and Scope of Study

Since there were no complete current records and inventories of the facilities and traffic flow in the Philadelphia CBD, it was necessary to do a fairly extensive research of various materials and to supplement it by a field survey. The sources of technical data about traffic in the Philadelphia CBD and the data required for the simulation model can be classified in three categories:

- i. Reports and literature included a number of reports by consultants and planning agencies of the City of Philadelphia which provided such data as traffic volumes, speeds and parking activities for several years. Several technical papers on the impact of small or compact vehicles on traffic flow were reviewed, but were not found very relevant since they were performed for freeway-type facilities with entirely different conditions than in high density urban areas.
- ii. City of Philadelphia and other public agencies were cooperative in providing such material as street widths, block lengths, parking facilities, area maps and other similar data. Traffic volume counts were also obtained from the City and from the Delaware Valley Regional Planning Commission, which has extensive data for the whole region, as well as some detailed information for the Philadelphia CBD.
- iii. Field survey had to be undertaken since a number of very important data were not available from any source or public agency. Despite the very limited size and facilities of the survey group, some of the data collected represent a more complete collection than any public agency presently has.

The field survey consisted of three phases. In the first phase, a detailed inventory of such items as traffic signal timing, parking regulations and various prohibitions for different times of the day, and the location of bus stops, were undertaken. This was performed by observation either from a moving vehicle or on foot.

The most extensive part of the study was the measurement of traffic speed and flow, including all relevant data on delays and their causes. It was decided to use the "average car" technique to measure travel time on 14 selected streets in the CBD. A total of 157 runs were made with at least three runs on each street for each of the three periods of the day: A. M. peak, midday average hour and P. M. peak. During each run one observer recorded the travel time, the number of stops made for traffic signals and the number of cars overtaken or passing the "average" test car. A second observer recorded the number of vehicles parked on each side of the surveyed street. The passing of each intersection was recorded on a magnetic tape using audible "marks" which ran continuously throughout each run. All other observations were also tape-recorded and later classified by analysis of the tape.



— SURVEYED STREETS

FIGURE SXI-1 STUDY AREA



Because of the significantly smaller size of the Minicar than standard automobiles, it is anticipated that it would have shorter time required for parking maneuvers. Therefore curb side observations were made of the parking time required for standard cars and of the starting delay, turning delay and platoon intervals experienced in mixed traffic.

## B. Results and Conclusions

### 1. Technical Results

a. Study Area and Street Network. The study area for which most of the data were collected coincided with the Philadelphia CBD. It is shown in Figure SXI-1. This area is bounded by Vine Street on the north, South Street on the south and the Delaware and Schuylkill Rivers on the east and west, respectively. The traffic survey, however, concentrated on selected streets within a somewhat smaller area: between Race Street on the north, Spruce Street on the south, 7th and 21st Streets on east and west, respectively.

Major streets in Central City are laid out in a rectangular grid pattern with a block size of approximately 450 x 600 feet and smaller streets (or alleys) at midblock locations. Only the Benjamin Franklin Parkway was laid diagonally on the rectangular pattern.

Most of the streets in the area are quite narrow. Over 75% of the length of streets in CBD have between 21 and 30 feet curb to curb width. This condition prevents identification of any street hierarchy. Most streets serve as arterials during peak hours and as access facilities at all times. These two incompatible activities necessarily lead to congestion. In order to improve traffic flow, most of the streets have been converted to one-way operation. Only some of the major arterials in the area presently have two-way operation. The streets selected for the field survey of traffic regulations, travel time and delay, and parking conditions are shown in Figure SXI-1. These streets were selected so as to include the main commercial streets (which follow the east-west direction) as well as two streets at the fringe (Race and Spruce) to compare traffic conditions in the core and at the fringes of the area. Since one of the main purposes of this study is to analyze high density traffic and the impact of short vehicles on it, an attempt was made to include all the streets of high density traffic, close to or in excess of their capacities. Such streets were selected by field observations and included in the surveyed facilities. Another criterion in selecting streets for the survey was the tentative location of terminals for the eventual MTS experiment.

b. Traffic Regulations. Data on the present operation of the signal system in Philadelphia CBD were not available from the City; consequently, a field survey was required to determine the present operation. From the consultants' reports made in the late 1950's, it has been found that the traffic signal control system encompassing some 300 intersections in the CBD was introduced in the mid 1950's. The system was supposed to provide a coordinated area-wide system with variable timing adjusted to the traffic volumes at different times of the day. This system is not in operation at present and all signals are operated on a fixed time basis. Most of them operate on a 60 second cycle, a few of them at larger intersections are timed for 80 second cycles, precluding coordination. The present limited coordination appears to be based on manual adjustment, but is frequently disrupted by the interventions of police officers (often undertaken on a random basis).

It is clear that the signal system in Philadelphia CBD is antiquated and entirely inadequate for the present traffic conditions.

c. Traffic Flow and Speeds. Traffic volume data from the City of Philadelphia were six years old but were the only available source of data on turning movement volumes and traffic composition and thus was gathered for each signalized intersection. Hourly volume counts of recent vintage were available from the DVRPC and were used to calculate the total average daily delay. According to the conversations with the Philadelphia Traffic Department and all available information, the AADT volumes on CBD streets have not changed significantly in the past decade.

Using the "average car method" described earlier, the survey data were collected, then tabulated and statistically analyzed. An examination of travel variance showed less variation on east-west streets than on the north-south streets; however, distance on north-south streets was only 1/2 that on east-west streets. Variation in travel time was significantly greater in the P. M. peak hours than during other periods except for the fringe area streets, Race and Spruce.

Average speeds for each street, by time of day, are shown in Figure SXI-2. A comparison of speeds on selected streets for 1957, 1963 and 1969 is shown in Figure SXI-3. It is interesting to note that the average CBD speed in 1929, according to Simpson and Curtin\*, was 9.3 mph.

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\* Simpson and Curtin, Traffic Signal Plan for the Central Business District (Report to the City of Philadelphia), May 1965.

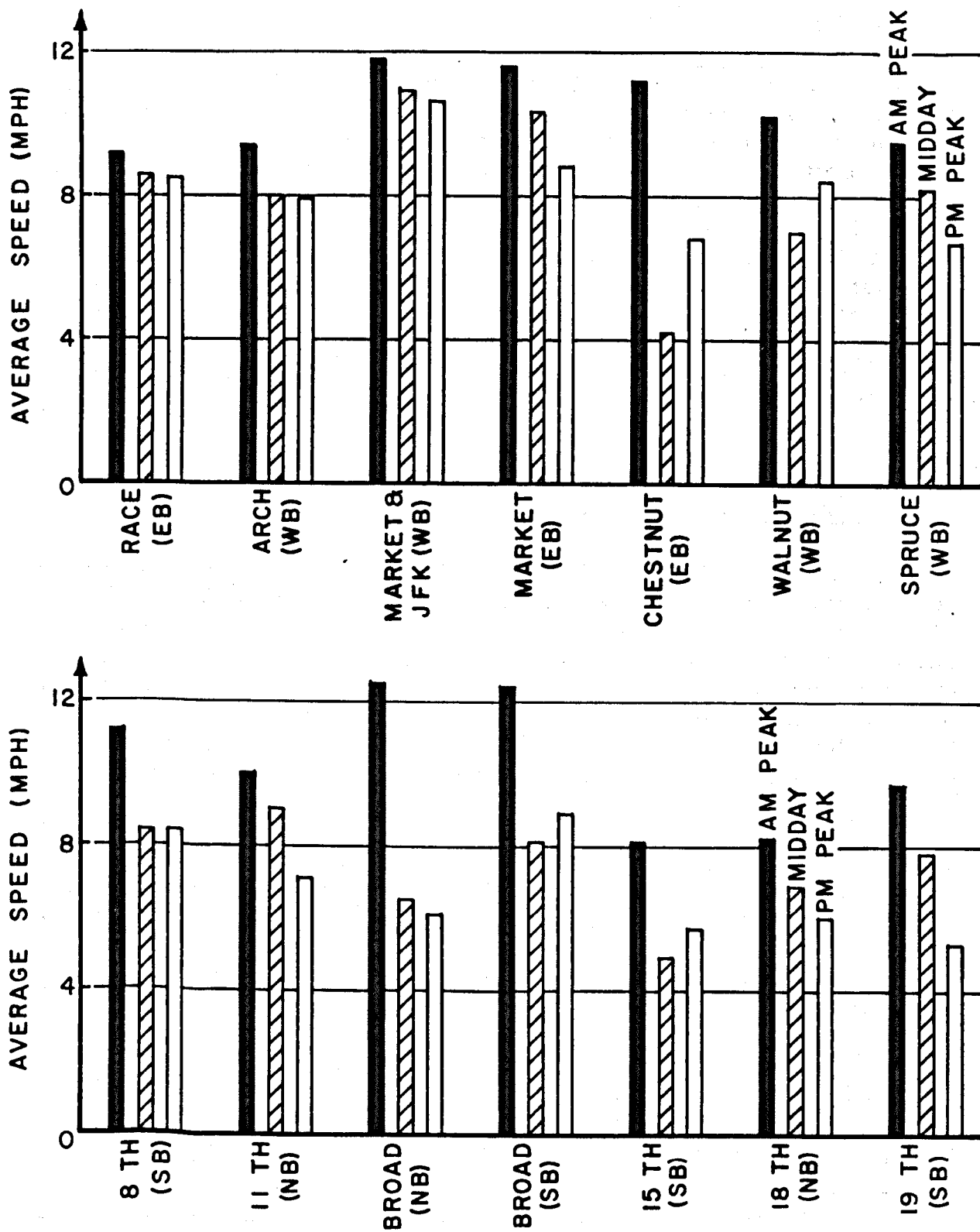


FIGURE SXI-2. SPEEDS ON SURVEYED STREETS

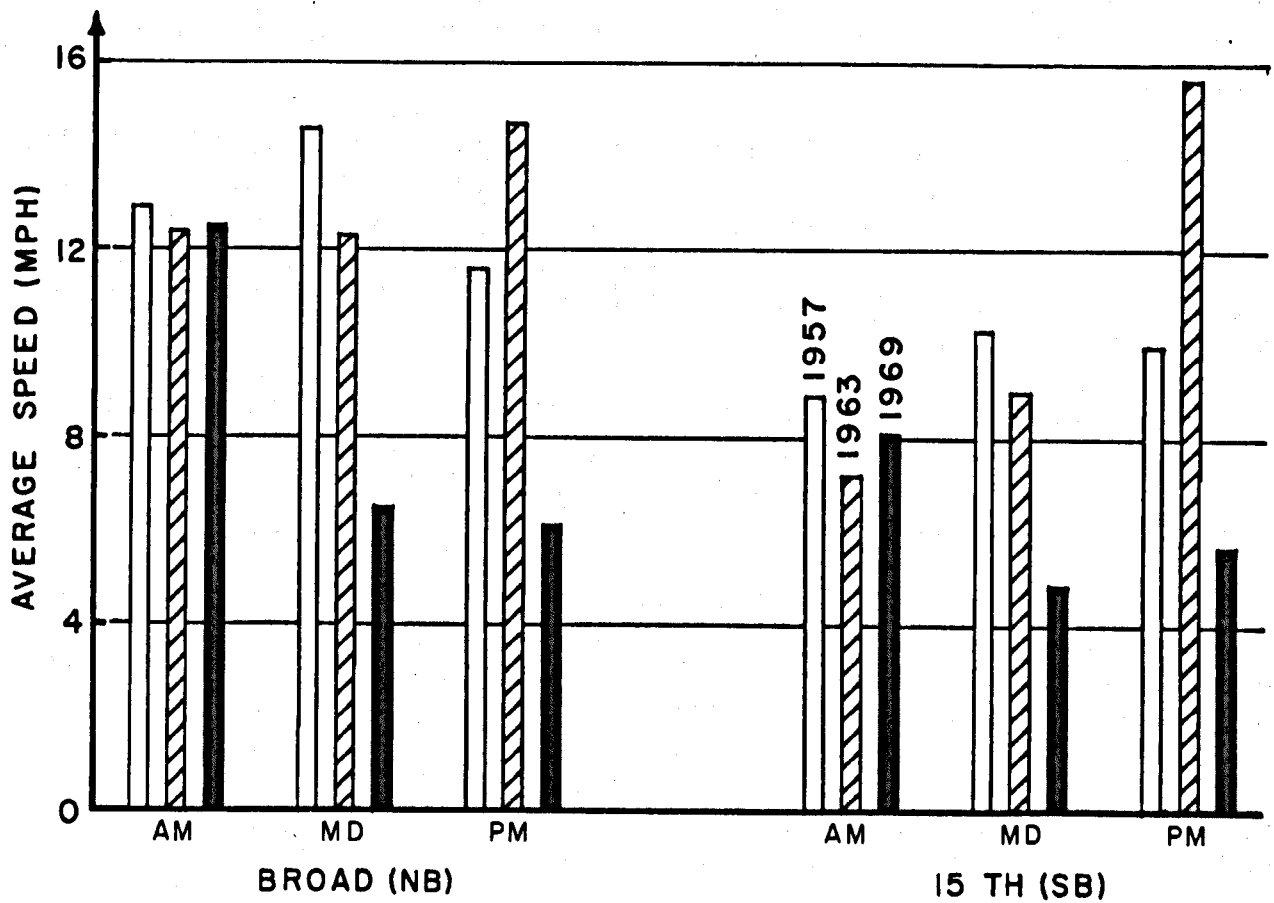
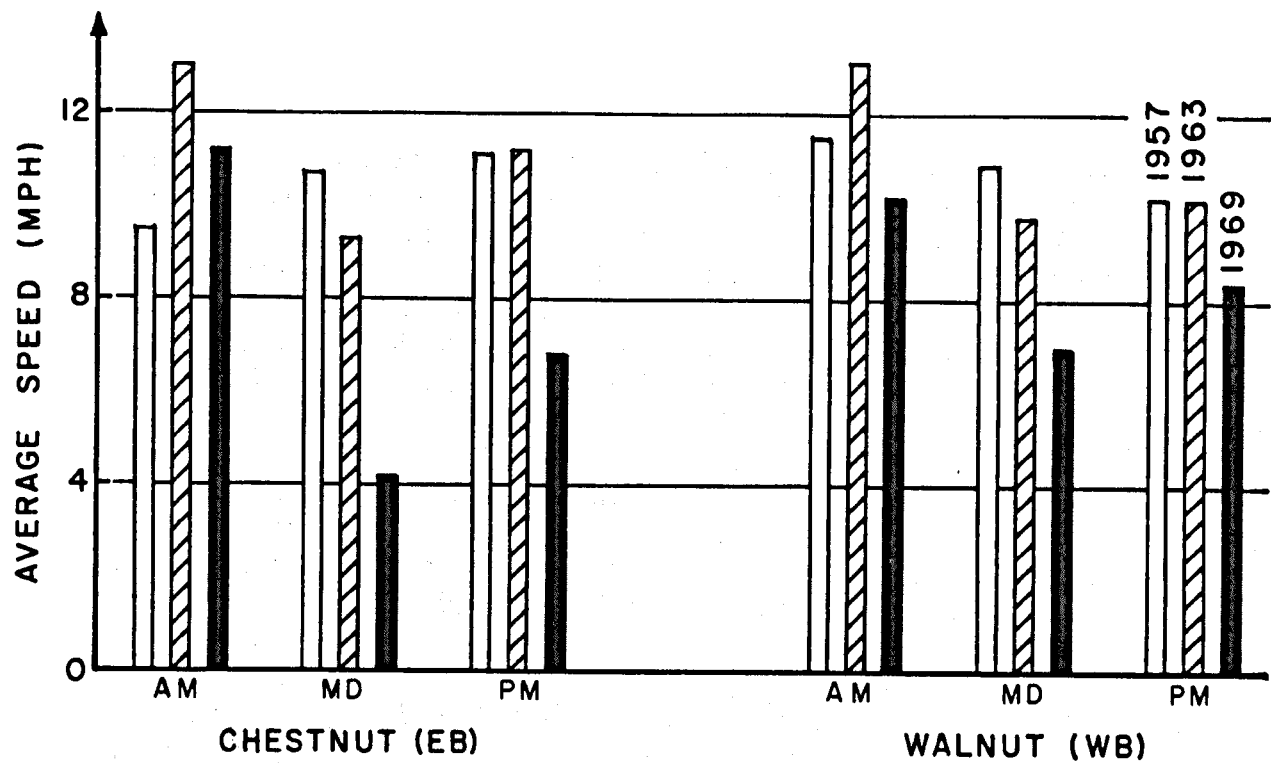


FIGURE SXI-3. COMPARISON OF SPEEDS ON SELECTED STREETS FOR 1957, 1963 and 1969

d. Parking. In an effort to obtain greater street capacity in the central business district, an ordinance was passed by the Philadelphia City Council in 1953 prohibiting all curb parking in the core area during normal business hours, 8:00 A.M. to 6:00 P.M. For a number of months the regulation was strictly enforced. Gradually, however, enforcement, and with it observance, of the regulations diminished. Today, violations of curb use regulations are frequent throughout the area, and discourage the use of curb lanes by moving vehicles.

The initial enactment of the blanket parking prohibition gave little regard to special street conditions or land use considerations, which might warrant variances in the regulations. Some secondary streets, not in the major street system nor used by vehicles in loading or delivery operations have the same regulations that are in effect along key arterials. The inequities in posted regulations were soon recognized by the driving public; they were acknowledged by the police in their enforcement program. As a result there is little uniformity of meaning, interpretation, or enforcement of similar traffic signs. This is disconcerting to motorists who are unaware of the multiple meanings of posted signs; it destroys respect for all regulatory signs.

Because of the difficulty in determining the legal status of vehicles stopped at curbside, all vehicles were considered to be parked if unoccupied or if the occupant indicated no intention to leave the curb space. Legally parked vehicles included those in metered spaces or in loading zones (including cab stands). Thus, the number of vehicles designated as legally parked will be conservative.

Curb spaces are provided only on the fringe (Spruce Street and Race Street) or on the West end of those streets wider than 26' (Market, JFK Blvd. and Arch). Legal core area parking is, therefore, restricted to loading zones and cab stands.

The average legal and illegal parking activity encountered during the survey is displayed graphically in Figures SXI-4 and SXI-5. Data in the project files also provide an analysis of activity by type of vehicle and in most cases the purpose of curb space use by commercial vehicles.

e. Traffic Conditions. The picture of traffic conditions today in the Philadelphia CBD is perhaps typical of U.S. cities with narrow streets and archaic traffic control methods.

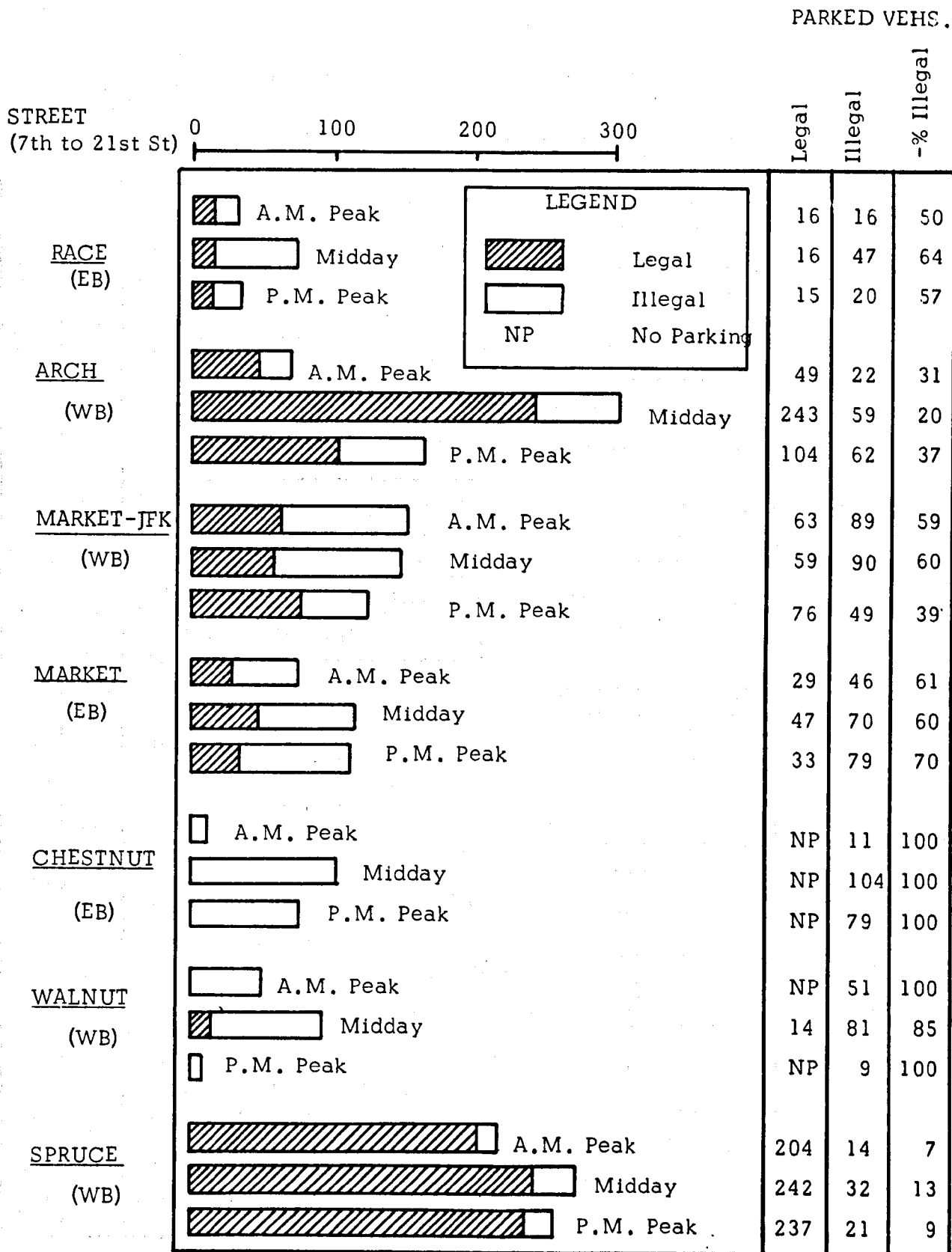


FIGURE SXI-4. LEGAL AND ILLEGAL PARKING, EAST-WEST STREETS

# PARKED VEH.

STREET  
(RACE ST. TO  
SPRUCE ST.)

0 50 100

Legal  
Illegal  
% Illegal

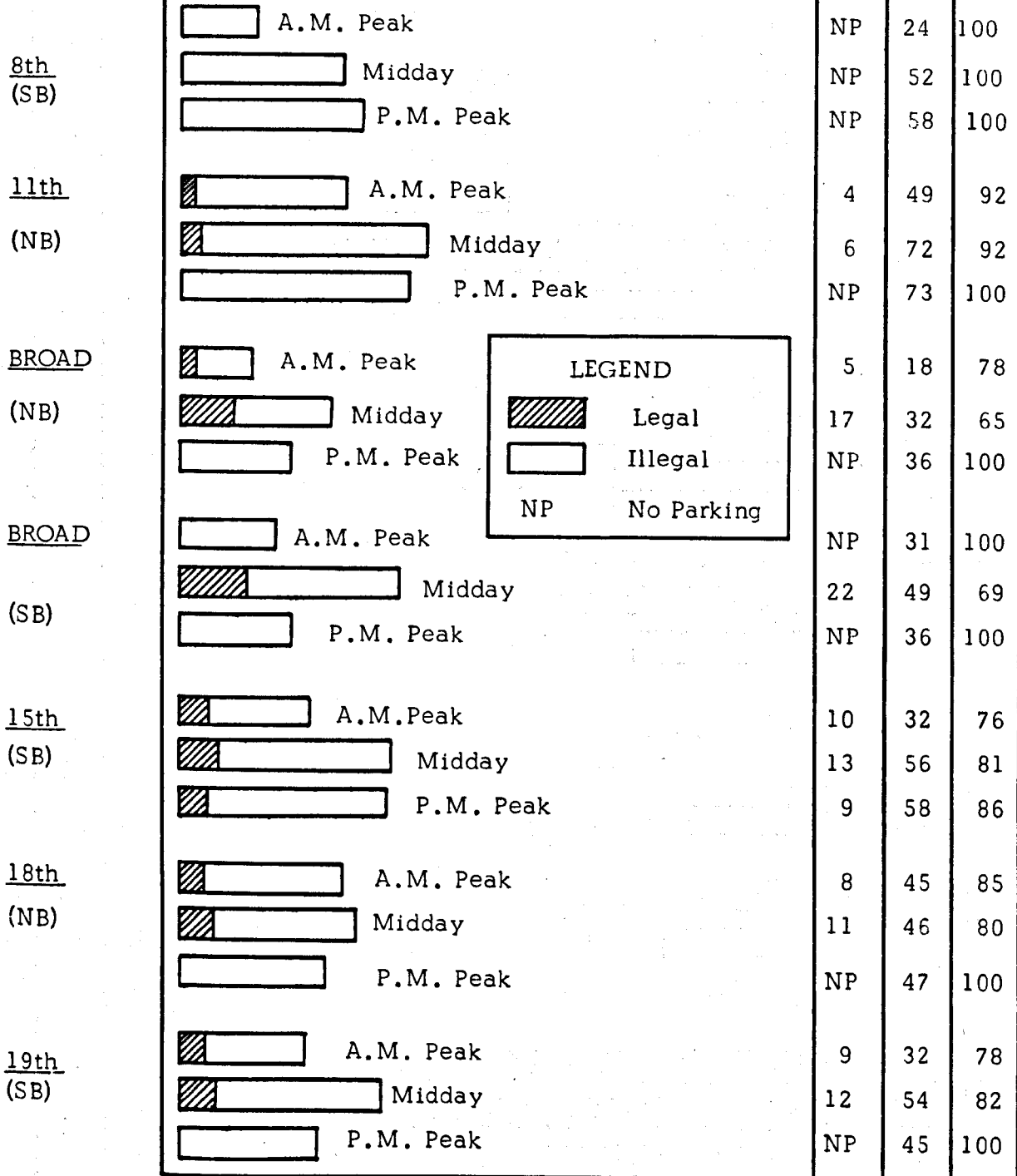


FIGURE SXI-5. LEGAL AND ILLEGAL PARKING, NORTH-SOUTH STREETS

The limited traffic flow data available indicated that, although some redistribution of traffic may have occurred because of changes in land use, the total CBD traffic volume has declined since 1956. The increased volumes around the Penn Center and Independence Mall redevelopment areas are not exceptions, since they apparently represent trips diverted from other CBD locations rather than new trips.

With few exceptions, speeds in the CBD have decreased since 1956 (and partly since 1963) and one could conclude that the average CBD speed is today approximately the same as it was in 1929. Since that time, removal of rail transit, creation of one-way streets, prohibition of curbside parking and relocation of bus loading zones have been instituted to ease congestion. The fact that traffic volumes have remained constant or decreased since 1956 without increased speeds indicates deficiencies in city control of traffic flow, street loading and parking.

Traffic conditions were found to be particularly sensitive to illegal parking. For example, the highest speeds and highest volumes occurred during the A.M. peak, the period of lowest parking activity. Conversely, at mid-day, when both automobile and delivery truck parking activities are highest, the speeds and volumes are at their lowest values.

## 2. Discussion and Conclusions

The data collected in this study were analyzed to determine the relative impact of various disturbances on traffic flow in the Philadelphia CBD. They indicated that curbside parking and poor signal coordination were the two primary causes of urban congestion.

The extent of illegal parking encountered indicates the poor enforcement procedures utilized and/or the lack of adequate zoning requirements for suitable off-street parking facilities. On Philadelphia's narrow streets, illegal parking of vehicles results in extremely poor lane utilization, preventing the use of curb lanes for storing vehicles waiting to make turns and forcing buses to maneuver into the center lane. On numerous occasions, the streets were observed to operate as one-lane cartways.

Since the maximum traffic volumes actually counted by DVRPC and the city reach only 70% of the rated capacity of the streets surveyed, it was concluded that:

- i) Significant CBD traffic improvement is possible by utilizing currently available traffic signals and by adequately enforcing present traffic and parking regulations.
- ii) Introduction of Minicar into the present traffic situation would improve flows within those lanes which are utilized but



would not have significant effect on the major disturbances which cause congestion. The MTS impact in Philadelphia would therefore be smaller than if traffic were adequately operated and controlled.

## COMPARISON OF ALTERNATIVE SYSTEMS

Short-haul passenger transportation in high density central urban areas is distinctly different by its characteristics and requirements from other transportation categories. High density of origins and destinations, high diversity of movements by direction and volume, need for ubiquitous and continuous service, etc., are some of the main characteristics. Despite these specific features of this transportation category, there is presently no available system which can adequately satisfy the need under most conditions in such areas. Several successful operations (e.g. minibuses in Washington, D.C., a streetcar line between a parking lot and downtown Fort Worth, Texas, and other cases) are more exotic examples of success than regular systems which solve the whole problem in most cities.

There is a general consensus that the existing modes (basically private automobiles and various modes of public transportation) as they are presently operated are not adequate to satisfy the need for short-haul transportation. This is one of the reasons that the mobility in the central urban areas is low, resulting in a number of problems.

Yet, the fact that there are very few satisfactory systems for short-haul transportation in operation does not necessarily indicate that there is a technological gap. A variety of systems proposed and considered at different times for this application exist and it is quite conceivable that some of these systems could be implemented successfully if different legal, organizational, economic, and other problems could be solved.

Since this study concentrates on all details of MTS application in urban areas, it is essential that an analysis be undertaken which will compare this System for short-haul transportation with all the other potential systems. Thus, even without going into great depth of analysis, it will be possible to estimate the advantages and disadvantages of rented individual vehicles as compared with other technological systems potentially usable for the same purpose.

### A. Method of Comparative Analysis

As the first step in this comparative analysis of systems, all requirements that such systems should satisfy are listed and briefly analyzed. The next step is selection and definition of the available transportation systems which could be used for this purpose. The systems, which are great in number, are grouped into parametrically defined functional categories. In subsequent Section the analysis itself is undertaken, on the basis of which the merits of those systems for short-haul transportation service in high density areas under different

conditions are discussed.

The evaluation of systems and their comparative analysis is based on the fundamental parameters defining the required level of service. Level of service is usually defined from the standpoint of users, but it cannot be limited to that. Factors concerning the operator of the system, as well as the indirect and intangible effects of the transportation system from the standpoint of non-users or, even more broadly, the city as a whole, must be included.

The number of requirements which could be included in the evaluation is so large that it creates conceptual and practical difficulties. The intention therefore is to use a method which has a small number of major parameters, which can further be decomposed into sets of "subparameters".

Three major tasks appear in the course of evaluation and comparative analysis of transportation systems, or more specifically, transportation modes. The first task is to precisely define each of the requirements. The second task is to quantify individual parameters for different modes in order to ease their comparison. The final task is to determine relative weights of characteristics, since they vary not only among themselves, but also from one city to another.

The comparison of individual parameters was made by assigning a monetary value to all parameters which can be estimated in such units; giving numerical values (such as travel time; area required, etc.) to all parameters which can be quantified in any other units; and, finally, the unquantifiable parameters were appraised by descriptive wording.

### 1. The Criteria

The following basic criteria of transportation systems for short-haul in urban areas have been selected as the most important ones for system evaluation:

1. Availability - the ease of obtaining transportation service. The basic measure of availability is how many persons can use the system (e.g. is it limited to drivers only). Further, it is measured by the distance a user must travel and the time he must wait in order to obtain such service. For a downtown circulation system, availability must be considerably greater than for long-haul service, since the trips are short and a potential user always has the option of walking. Therefore, limits of acceptability of walking distance and travel time are quite low. It is desirable that the system has as close as possible a ubiquitous and continuous service.

2. Travel Speed - total distance traveled divided by total travel time. Distance includes access, distance traveled on the system, and distance to final destination. Total travel time includes access time, waiting time, time spent on the system including transfers, and time to arrive at final destination. Due to short length of CBD trips, terminal times have greater relative significance than running speed of the system.

3. User cost - in most cases this is the fare and/or parking fee. Factors related to this item which should be considered are level and structure of the fare, acceptability of imposition of fare by the public as well as ease of fare collection.

4. Comfort and convenience - these two elements refer to the physical conditions as they affect the persons who travel. They include physical and mental well-being of the passenger and very few of their aspects can be quantified.

5. Safety - this factor is measured by the number and seriousness of accidents per unit of travel. It is a very important item in passenger transportation.

6. Reliability - measured by "infrequency" of disturbances or breakdowns in service, reliability can be divided into: reliability of service, infrequency of breakdowns and reliability in emergencies. For short-haul transportation it is important that consequences of breakdowns should not be very serious.

7. Side effects - this group of factors refers primarily to the effects which the system has on non-users, not only users. It includes such factors as air pollution, noise, external esthetics, etc. In central areas, all these factors are of relatively high importance.

8. Capacity - transporting capacity (maximum number of persons that can be transported past a point per unit time) is very important for short-haul systems since demand is not only high but also highly peaked. The system should accept the peak demand without excessive delays or inconvenience.

9. Technological feasibility - two major aspects are included in this criterion: feasibility of using the transportation system under the conditions existing in high density central urban areas, and technical feasibility of the system itself; the latter one is important for some of the proposed and not yet tested systems.

10. Investment cost - cost of implementing full operation of a system-right-of-way cost, construction cost, equipment cost, and start-up costs.

11. Operating cost - cost of performing transportation service-labor, maintenance of way and equipment, power, administration, etc.

12. Public acceptance - degree to which the people will accept and use a system. This is an important factor for passenger transportation systems, but it may be difficult to predict.

13. Implementation - total effort, cost and time which must be invested to make the system operational; this includes not only technical problems, but political, legal, social and other problems as well. Also, ease of introduction of a system into the urban environment, including length and intensity of construction process and adaptability to stage construction, which are often critical for systems in CBD areas.

14. Other factors - this category includes all significant factors not included in the above criteria, such as, for example, sensitivity of the system to terrain, climate, etc. Most of these factors are related to local conditions and cannot be generalized.

## 2. Definition of Systems

All transportation systems which could conceivably be considered for application in central urban areas have been included in the analysis. They range from such standard systems as transit bus to the novel systems of untested practical value such as the Transit Expressway and Transdrive. It is easy to notice, however, that nearly all of these diversified systems can be fairly accurately grouped into several categories by their type of operation. Thus, it was decided to group all the systems by their characteristics into several parametrically defined categories. For example, rail rapid transit, various monorails, zero system, mini-rail and Westinghouse Transit Expressway are all public transport vehicles operating on private right-of-way. Most of their basic operational characteristics are the same.

The eight System categories were defined as follows:

### 1. Pedestrian modes

A. Walking;

B. Assisted walking; including those devices which serve for distances within or somewhat over acceptable walking distance; they would supplement rather than supplant walking.

## 2. Public Vehicle Systems

- A. On private right-of-way;
- B. Partially on private right-of-way and partially on surface streets;
- C. On surface streets.

## 3. Individual Vehicle Systems

- A. On private right-of-way;
- B. Partially on private right-of-way and partially on surface streets;
- C. On surface streets.

A list of the considered potential systems for short-haul transportation grouped into these eight categories is given in [R-5, Appendix].

### B. Comparative Analysis

The best available data for all considered systems were collected and the systems were analyzed with respect to each of the fourteen evaluation criteria. This analysis is fairly complex and it requires considerable experience and judgment in some items, particularly with the unquantifiable elements of the system. Its final results are presented in a summarized form in Table S XII-1. The table illustrates the general method used in the analysis. For ease of comparison, five standard wording appraisals have been used in the Table (very poor, poor, fair, good and very good) for evaluation of each element.

It was one of the basic goals of this study to analyze transportation systems which could be easily implemented. This condition, if strictly followed, tapers down the choice of the analyzed systems to only three categories: walking, public transport on surface streets and individual vehicles on surface streets. All other systems would require considerably more investment cost and implementation time.

Conclusions reached about the four systems which would require least investment and time to implement - MTS, Minibus System, existing public transportation service, and walking - will be summarized in the following sections.

#### 1. Minicar Transit System

Minicars would most likely be rather popular with the public for trips

TABLE XII-1. COMPARATIVE ANALYSIS OF SHORT-HAUL TRANSPORTATION SYSTEMS

System Requirements	Pedestrian Modes		Public Transport - Discrete Operation			Individual Vehicles		
	Walking	Assisted Walking	Private R.O.W.	Partially Private R.O.W.	Surface Streets	Private R.O.W.	Partially Private R.O.W.	Surface Streets
1. Availability	Very Good	Very Poor	Poor	Fair	Good	Poor	Fair	Fair
2. Running Speed (mph)	3	2 - 15	15 - 20	12 - 15	6 - 12	20 - 60	15 - 30	8 - 20
3. User Cost	Very Good (none)	Good	Very Good	Very Good	Good	Fair	Poor	Poor
4. Comfort	Poor	Fair	Very Good	Very Good	Fair	Very Good	Good	Poor
Convenience			Good	Very Good	Very Good	Very Good	Fair	Poor
5. Safety	Fair	Poor	Very Good	Very Good	Good	?	Fair	Poor
Security	Poor	Good	Poor	Fair	Good	Very Good	Very Good	Very Good
6. Reliability	Very Good	Good	Very Good	Good	Poor	Good (untested)	Fair	Very Poor
7. Side Effects	Very Good	Good	Good	Fair	Poor	Fair	Poor	Very Poor
8. Capacity (in thousands of people)	1.0/hr/ft. width	3.6/hr/22"	30.0/hr/track	15.0/hr/track	5.0/hr lane	?	?	1.5/hr/lane
9. Technological Feasibility	Very Good	Poor	Very Good	Very Good	Very Good	(no space) Poor	?	Very Good
10. Investment Cost	Very Good (low)	Very Poor	Very Poor	Poor	Very Good	Very Poor	Very Poor	Poor
11. Operating Cost	Very Good (low)	Good	Good	Fair	Poor	?	Poor	Very Poor
12. Public Acceptance	Poor	Good	Very Good	Good	Poor	Very Good	Good	Good
13. Implementation	Very Good	Fair	Very Poor	Poor	Very Good	Poor	Fair	Very Good
14. Other Factors					(cannot be generalized)			

similar to those performed by taxis. Their significant advantage over the private automobile would be flexibility of use-easy "disposability" - and easy handling due to small size. Similar to private automobiles however, they would not be convenient for very short trips due to long terminal times, and in the areas of very high density they would not be capable of providing adequate capacity. Minicars would, therefore, be convenient only for a limited number of trips, mostly those with dispersed trip-ends, in high density central areas. This limited use could be achieved by a higher pricing level at the terminals in such areas. Consequently MTS could not offer a total answer to short-haul transportation needs in central business districts.

## 2. Area-Wide Minibus System

a. Introduction - Comparative analysis of alternate systems for short-haul passenger transportation has shown that for immediate application in urban areas minibuses may be one of the best solutions. The appraisal of this transportation system was positive enough to justify one step further in its analysis. The purpose of this analysis is to determine feasibility and desirability of this system's application in the Philadelphia CBD and briefly compare it with the Minicar Transit System.

In order to provide a comparison of the two systems, they had to be made as comparable as their diverse technology and types of operation permit. The two systems should offer comparable service to the users in terms of their ubiquity, frequency, convenience, cost and other elements of level of service. Network of lines, frequency of service and other parameters of Minibus system have been selected on that basis.

A number of various minibus systems have been introduced in different cities in the last few years. One which has been perhaps most successful and for which excellent data are available is the Minibus in Washington, D.C. (on F Street)\*. The area which it serves is in many respects similar to several sections of Philadelphia CBD. It was therefore decided to make use of the data from that system (running and commercial speed, cost structure and level, operating times, etc.) for this comparative analysis. Each of the parameters was critically discussed and accepted or modified for the model of Philadelphia CBD service.

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\* The Minibus in Washington, D. C., Final Report on a Mass Transportation Demonstration Project DC-MTD-2, 1965.



b. The Area and Network of Lines - The study area is the Philadelphia CBD, or Zone A, as defined by DVRPC; it is delineated by Vine Street, Schuylkill River, South Street and Delaware River.

The lines are laid out in the north-south and east-west direction, respectively, following the street grid iron pattern. Because of the extensive one-way street system within this area, the lines form a series of loops utilizing adjacent parallel streets for running in opposite directions. Due to the discontinuity of some of the streets, one-way operation and other local conditions, certain modifications of this regular pattern were necessary.

A complete description of the line routings is shown in Figure S XII-1. It can be noted in the Figure that despite minor deviations, the pattern of line routings still remains basically regular and simple for passenger orientation.

Since the service has been provided on each street in the area, the average access distance to a line is approximately 200-300 feet; the average walking time is thus 1 minute.

c. The Service - While headway on each individual line should depend on the passenger volume and thereby be different for different lines, if a certain minimum level of transportation service with respect to the frequency of service is to be provided in an area, a uniform headway for all lines must be adopted. The uniform headway should therefore be considered as the minimum headway. Additional buses may be put in, reducing headways on the lines on which passenger load requires.

It was considered that if the system is to provide a high level of service for relatively short trips, comparable to that of elevators, so that passengers can rely on short waiting times, a uniform headway should not exceed four minutes. With regular service this headway provides for an average waiting time of two minutes. With disturbance in service the statistical average of waiting would tend to slightly exceed two minutes, but still remain within an acceptable length of time for this type of service.

Operating speed of Washington Minibuses is  $V = 4.3$  m/h. This low speed is caused by frequent stops, heavy passenger loads and difficult traffic conditions on F. Street. One could expect that conditions on Chestnut, Walnut and some other streets in Philadelphia CBD would be comparable to those on F Street. On other streets with lighter passenger loads, one-way operation and with better coordination between signal timing and minibus running, higher speeds could be realized.

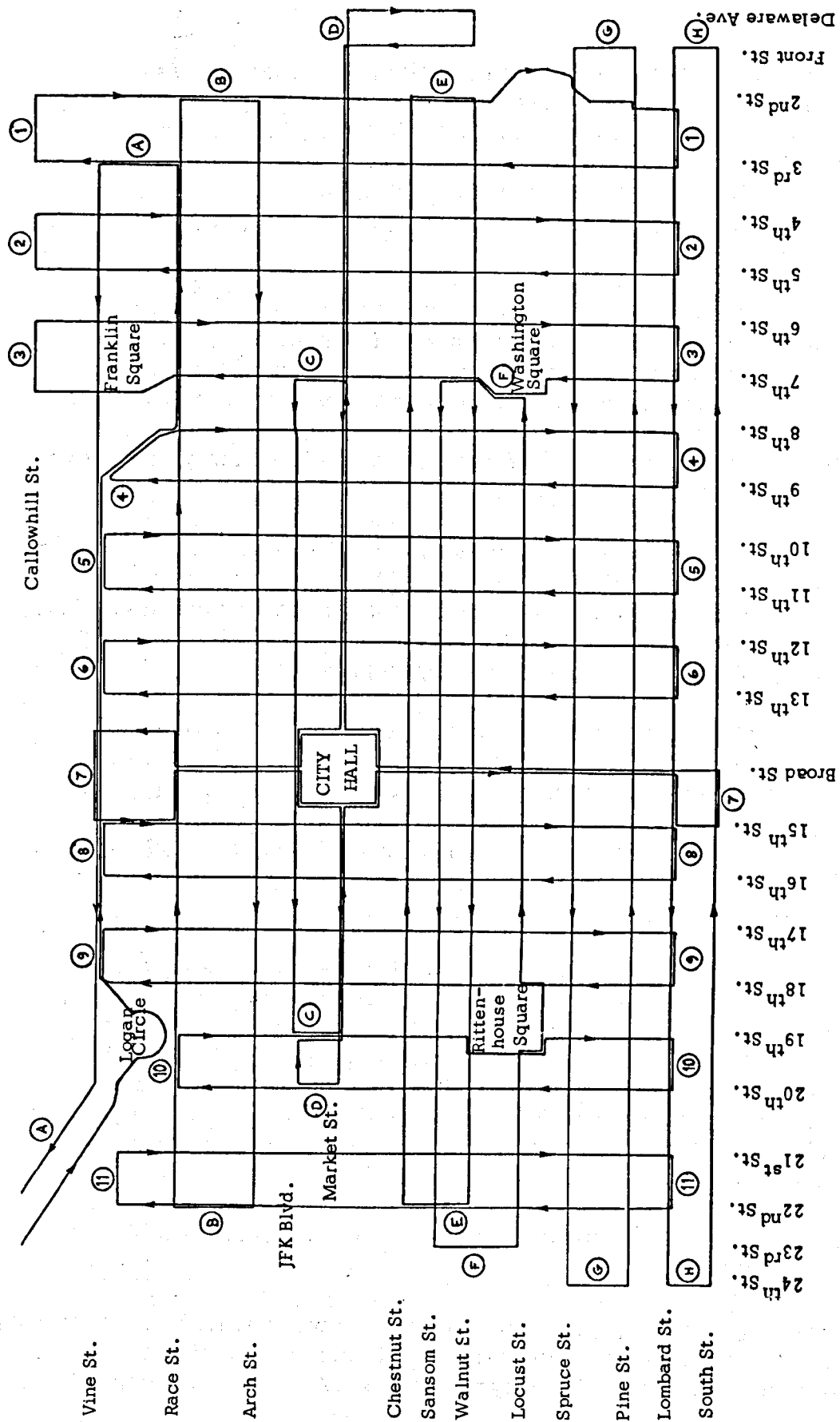


FIGURE SXII-1. NETWORK OF MINIBUS LINES

Another guide in selecting operating speeds are actual speeds of transit vehicles in the study area. These speeds vary from approximately 4 m/h on Chestnut and Walnut Streets and 5-8 on Broad, to 6-11 on 10th and 11th Streets. These data are based on surveys by Wilbur Smith and Associates are old (1957), but the information obtained specifically for this study indicates that in general the present speeds are approximately within the same range.

Minibuses might have lower speeds than standard surface transit due to frequent stopping and heavy interchanges of passengers. On the other hand, they have the advantage of better design for loading-unloading (shorter delay per passenger); they also have some advantage due to smaller dimensions and better performance for high density traffic. It is therefore not expected that the operating speed of minibuses would differ greatly from that of standard surface transit vehicles.

Based on these considerations, it was decided to make computations for two speeds: 4.3 m/h - based on Washington Minibus, and 7 m/h - considered a probable average for an area-wide service in Philadelphia CBD. Thus, the first computation can be considered as the "conservative limit" and the second as probable value of minibus operating speeds.

Layover time at terminal points was computed as 10% of the total round trip running time, but not less than 5 minutes. These values are based on standard practices for this type of transit service.

Time of operation was expected to be from 7:30 A.M. to 6:30 P.M., i.e., 11 hours. There is no night service. This follows the practice applied in Washington, D.C.

d. Costs - The report on Washington Minibuses provides a complete breakdown of costs which has been used as the reference in this analysis. The cost breakdown indicates that only 5.6% of the total costs including operation and rental (depreciation) are mileage - dependent. Cost per bus-hour is, therefore, a better figure to use in this analysis than cost per vehicle mile. Cost of bus-hour was \$5.73. Applied to an area-wide system, this figure should be on the conservative side since a larger operation would permit economies of scale.

Computations for the two different operating speeds, 4.3 and 7.0 m/h, were made for all routes.

e. Results and Conclusions - The analysis shows that with the operating speed of 4.3 m/h the system would consist of 230 buses operating a total of 2289.8 hours per day. The cost of the system (at \$5.73/bus hour) would be

\$13,120/day. With the operating speed of 7.0 m/h, 152 buses would operate only 1518.7 hours and the total cost would be \$8700/day.

The derived figures indicate that the described minibus system would operate at break even point with the following numbers of passengers per day:

Fare (incl. transfer)	Number of passengers/day at:	
	$V_o = 4.3 \text{ m/h}$	$V_o = 7.0 \text{ m/h}$
\$0.10	131,200	87,000
0.15	87,500	58,000
0.20	65,600	43,500
0.25	52,480	34,800

If the projected daytime demand for intra-CBD person-trips by Minicars (32,850/day) at an average fare of \$0.75\* were served by Minibuses, the fare at which the system would break even would have to be about \$0.25 at  $V_o = 7.0 \text{ m/h}$ . Person trips between fringes and CBD (80,992/day) could not, however, be served by minibuses as efficiently since they would require transfer to another means of transportation outside the CBD. Demand data are from Reference [R-1, Figure 25].

Reliability of the figures used in this analysis is limited by the fact that the data applied have been taken from another city and another set of local conditions. However, one should assume that these figures are at least as reliable as those used in the analysis of the MTS for which no experience exists. The analysis, therefore, while requiring much more detailed work, does serve as an order-of-magnitude examination of the minibus system.

Direct impact of the movement of minibuses on street traffic would be negligible. They would constitute approximately 2-4% of the vehicles. Effect of their frequent stopping would be minimized by their flexibility of movement. Their service would, on the other hand, cause diversion of some automobile trips; thus the total vehicular traffic volume in the area would be reduced.

Comparing the analyzed system of minibuses with MTS one can conclude that minibuses would provide:

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\* Based on \$0.50 for the first 1.25 mile plus \$0.25 for each additional mile.

- (1) Service limited to CBD only, i.e., transfer needed for outside trips;
- (2) Comparable area coverage;
- (3) Service limited to the day hours;
- (4) Transportation for everybody (not drivers only);
- (5) Lower comfort of ride, no privacy;
- (6) Considerably lower fare (25¢ instead of 50¢-\$1.00).
- (7) Lower traveling speed, but also shorter terminal times.
- (8) Comparable convenience (no door-to-door service, but simple use);
- (9) Lower social cost (space requirements, congestion);
- (10) Higher reliability;
- (11) Higher safety.

As mentioned earlier, a detailed analysis of a minibus system for the Philadelphia CBD is not in the scope of this study. However, the comparative analysis of alternative short-haul transportation systems and this brief analysis do clearly indicate that minibus system is at least highly competitive with any other system applied for this purpose and if a transportation system exclusively for CBD short-haul is planned, application of minibuses should be studied in further detail.

### 3. Existing Public Transportation Service

Perhaps the greatest advantage of public transportation is the ease of its use: passenger gets on and off the vehicle without need for searching for parking space, locking the car, etc. This is, however, the case if three conditions are satisfied: that network of public transportation is dense enough (availability is high), that potential users are informed about the service, and that its price and level of service are acceptable.

In the case of Philadelphia as well as most major cities, the first condition, area coverage, is quite satisfactory. In central Philadelphia, service is provided on nearly all major streets and the frequency of service is quite high. The other condition, that users are informed about the service, is quite different. Despite the fact that the street network in Philadelphia is very regular, the existing information for the public has numerous deficiencies and this is certainly one of the reasons for relatively low use of public transportation service for short-haul transportation. Speeds of transit on surface streets are low, but not too low in comparison with other modes which are utilizing the same network. The third condition for use of public transportation services for short trips is the fare. Flat fare is typical not only for Philadelphia but also for other U.S. cities. Such fare is the same for a trip of 3-5 blocks as the one for 10-12 miles across the City. Consequently, for short trips within the City, such fare is too high. Very interesting observations of this problem are available in London: a great majority of users of London buses pay the minimum fare, which is approximately 6 cents, or 20% of the 30¢ fare,

typical for American cities.

Since there would be major benefits to the users, to the traffic conditions in the City and to the public transportation operator if more short-haul users were attracted to public transportation systems, it is suggested that serious attention be given to the improvement of the two measures which could correct this deficiency:

- (i) Introduce special low fares (10¢ or 15¢ at most) for trips within the central area;
- (ii) Improve information about public transportation services and make it easily available to the public.

Both of these steps are easy to implement and their results would be a very useful demonstration of the potential of better utilization of existing facilities in urban centers at an extremely low investment cost.

#### 4. Walking

It has been found that for transportation in high density central urban areas significance of walking cannot be over-emphasized. In analyzing all systems, walking proved to be an important element. The main problem of walking, and one of the main reasons that walking longer distances is becoming less attractive in urban areas, is that this mode of travel has been seriously neglected.

Acceptability of walking by the public largely depends on the area in question. In attractive areas (some central cities, shopping centers and recreation areas) people are ready to walk considerable distances and enjoy it. If they have to walk through a congested area, unkept sidewalks, have to cross streets under unsafe conditions, etc., reluctance toward walking is understandable.

A detailed analysis of walking is not within the scope of this study. The conclusion cannot be avoided, however, that improvement of walking conditions would contribute very significantly to the success of any technology applied for short-haul transportation. Walking as such requires a serious and much more comprehensive study than any (known to have been) undertaken by the time of this study.

### C. Conclusion

Any system of transportation operating on the street network is subject to the "friction" from other activities and existing control measures. Efforts to improve these conditions and enforce suitable regulations would not penalize automobiles users but cause them to bear the full cost of their trip. The result should be a general increase in mobility and an improvement of the economic vitality of the CBD area.

An area-wide system of minibus services appears to be physically and economically quite promising as a fast relief to CBD congestion, although such a service would probably not prove its maximum efficiency in a very short period of time; its value would be in its long-range effects on the whole area. Economic and social activities in the area would greatly benefit if such a system were provided.

The existing public transportation service in the Philadelphia area is adequate to satisfy a large portion of the demand for short-haul transportation. This is probably the most logical solution to the problem, but it could be materialized only if special fares and better information systems were introduced. This should not be a major problem.

Finally, the importance of walking in the central areas has been too often neglected. Additional studies of pedestrian behavior and their interface with vehicles should be undertaken. Means of mechanically assisting walking, such as moving sidewalks, should also be investigated.

It is obvious that improvements in CBD short-haul transportation can be achieved in several ways with relatively small investments. The organizational changes required are not unrealistic: they could be achieved by energetic action of the city government and cooperation of the transit agency.

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